Biomass accumulation and carbon stock in different agroforestry systems prevalent in the Himalayan foothills, India

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Agroforestry has great potential for carbon (C) sequestration among different land uses of the Himalayan region, India. However, our knowledge of C sequestration in particular, agroforestry system around the world is poor. Therefore, we conducted a study to understand biomass accumulation and carbon allocation in different components of the agroforestry system. The highest stem biomass was recorded in *Eucalyptus tereticornis* (69.43 ± 0.90 Mg ha^{-1}), branch biomass in *Populus deltoids* (5.04 ± 0.35 Mg ha^{-1}), leaf biomass also in *P. deltoids* (2.21 ± 0.12 Mg ha^{-1}), and root biomass in *Albizia procera* (14.01 ± 0.44 Mg ha^{-1}). The highest (81.01%) C allocation was recorded in the stem of *Toona ciliate*, branch of *P. deltoids* (5.73%), leaves of *E. tereticornis* (2.93%) and root of *Anthocephalus cadamba* (16.83%). The highest CO_2 mitigation (160.5 ± 2.55 Mg CO_2 ha^{-1}) and C sequestration (45.33 ± 0.60 Mg ha^{-1}) were recorded in *E. tereticornis*. The highest wheat crop biomass (11.85 ± 0.23 Mg ha^{-1}) and C stock (3.59 ± 0.05 Mg ha^{-1}) were recorded in *P. deltiodes*. However, soil carbon stock was recorded in *E. tereticornis* (37.5 ± 3.52 Mg ha^{-1}). Thus, trees on farmlands with crops are suitable for biomass production and C allocation in different components under changing climatic scenarios.

Keywords: Agroforestry system, biomass, carbon stock, carbon dioxide mitigation, climate change.

THE carbon stored in soil and biomass under agroforestry is substantially greater than the sole cropping system. In India, the average carbon sequestration potential in agroforestry has been estimated to be 25 tonnes per hectare over 96 m ha^{-1} area[1]. However, these estimates are mostly derived from biomass productivity and not from the soil stocks. Generally, carbon may be sequestered in mineral soil after conversion from intensively cultivated agricultural fields to more comprehensive land uses such as forested ecosystems[2]. Biomass stock and its storage rate play an important role in fulfiling the rising demand for tree products and in mitigating the climate change problem. Therefore, it is imperative to assess biomass accumulation in different agroforestry systems. Promoting agroforestry is one of the options to resolve land use and CO_2-induced global warming issues[3]. Any type of agroforestry system can yield carbon credits from the inclusion of trees in farmlands, and the overall carbon stock of the ecosystem would increase in the trees and soil.

Wheat is one of the agroforestry crops grown in the foothills of the Indian Himalaya. It is intercropped with different tree species during *rabi* season and in this intercropping, both trees and crops compete for available light and soil resources (water, nutrients, etc.)[4].

There is little information on the accumulation of biomass and carbon stocks in various agroforestry systems. Current information is only available for tree species and not their various components and the understorey crops. Keeping this in view, we conducted the present study to evaluate biomass accumulation and carbon stock under different components of agroforestry which are prevalent in the Himalayan foothills of India. The study was undertaken with the following objectives: (i) to quantify the biomass of different components of the agroforestry system, and (ii) to measure carbon stock in the biomass as well as in soils of different agroforestry systems.

This study was conducted on agroforestry systems practiced by farmers in Dhanauri range of Haridwar district, Uttarakhand, India. Dhanauri is situated at 29.94 N lat. and 77.95 E long. with an altitude 249.8 m amsl in the foothills of the Indian Himalaya. It falls in the sub-humid and sub-tropical climatic zone of the country.

In this study, we selected eight different agroforestry systems. Wheat (*Triticum aestivum*) is the main agricultural crop that is intercropped with trees in this area. We estimated the above- and below-ground biomass of these eight agroforestry systems, i.e. *Populus deltoids*, *Toona ciliata*, *Eucalyptus tereticornis*, *Albizia procera*, *Melia azedarach*, *Terminalia bellirica*, *Anthocephalus cadamba* and *Sapindus mukorosi*. These agroforestry tree species were planted at 4×4 m spacing in 2007. Earlier, in all the agroforestry systems, farmers had used wheat, sugarcane, soybean, potato, jowar and turmeric as intercrops. However, in the present study, we considered only wheat crop that was intercropped in all agroforestry systems, since the farmers were now growing only this crop.

The biomass of each component (stem, branch and leaf) of the trees was calculated by destructive sampling. All the tree species were replicated thrice (three trees were harvested for each tree species). After felling, above-ground parts, viz. stem, branch and leaf were separated. The stem was then cross-cut into logs of appropriate length depending upon its general form. The fresh weight of each log was taken in the field for each sample tree with the help of heavy weight spring balance. Three cross-sectional discs representing the top, middle and bottom portions of the tree stem were taken from each

Table 1. Biomass of different agroforestry components (Mg ha^{-1})

Agroforestry system	Tree species					Wheat crop		
	Stem	Branch	Leaf	Root	Total	SLG	Root	Total
Populus deltoides	66.8 ± 0.45^a	5.04 ± 0.35^a	2.21 ± 0.12^b	11.03 ± 0.28^{bc}	85.0 ± 1.94^b	9.81 ± 0.17^a	2.04 ± 0.16^a	11.85 ± 0.23^a
Toona ciliata	62.06 ± 1.26^b	3.66 ± 0.63^b	1.94 ± 0.10^b	9.39 ± 0.31^c	76.45 ± 1.17^c	8.56 ± 0.17^{cd}	1.23 ± 0.02^c	9.79 ± 0.15^d
Eucalyptus tereticornis	69.43 ± 0.90^a	3.63 ± 0.36^b	2.85 ± 0.08^a	11.22 ± 0.02^a	89.43 ± 0.28^a	9.18 ± 0.13^b	1.66 ± 0.11^b	10.84 ± 0.22^b
Albizia procera	53.42 ± 1.31^{cd}	3.34 ± 0.22^{bc}	1.86 ± 0.17^{bc}	14.01 ± 0.44^c	68.18 ± 0.85^d	8.26 ± 0.12^d	1.35 ± 0.03^c	9.61 ± 0.11^d
Melia azedarach	50.13 ± 0.94^{de}	3.07 ± 0.28b^c	1.45 ± 0.10^{cd}	9.68 ± 0.33^c	64.94 ± 0.72^{ef}	8.37 ± 0.14^d	1.22 ± 0.02^c	9.59 ± 0.14^d
Terminalia bellirica	48.2 ± 0.40^e	2.41 ± 0.56^c	1.29 ± 0.17^d	9.98 ± 0.06^c	62.07 ± 0.81^f	9.04 ± 0.09^b	1.42 ± 0.02^c	10.46 ± 0.11^{bc}
Anthocephalus cadamba	55.68 ± 0.26^c	4.07 ± 0.28^{ab}	1.89 ± 0.15^b	12.53 ± 0.76^{ab}	74.0 ± 0.40^d	8.50 ± 0.12^{cd}	1.26 ± 0.03^c	9.76 ± 0.13^d
Sapindus mukorosi	52.25 ± 0.08^{cd}	3.0 ± 0.31^{bc}	1.15 ± 0.09^d	9.58 ± 1.14^c	67.37 ± 1.19^e	8.92 ± 0.16^{bc}	1.41 ± 0.02^c	10.33 ± 0.17^c

SLG, Stem, leaves and grain. Different letters indicate significant differences ($P < 0.05$) between species. Data with the same letters in the superscript do not differ significantly.

tree to determine moisture content. The same process was also followed for branch and leaf to determine biomass and moisture. Using a JCB machine, the roots of each tree species were dugout to determine the below-ground biomass. All the main roots and fine roots were collected and weighed using a weighing machine to obtain the fresh weight of roots. A known quantity of samples was oven-dried to obtain the biomass of roots. The above- and below-ground biomass of wheat crops was determined by laying out three quadrats (1 × 1 m size) in each agroforestry system.

Carbon concentration in all components of each tree species was determined by combustion method[5].

Biomass of different tree components and their carbon concentration were multiplied to estimate carbon stock in each component[6]. Carbon dioxide (CO_2) mitigation by different agroforestry systems was estimated by multiplying the values of carbon stock by a factor of 3.66 (ref. 7). Total carbon sequestration (Mg ha^{-1}) in woody component was estimated by adding long-lived carbon storage in wood products and the carbon storage due to substitution biomass for coal[8]. The carbon stock in the soil was computed using the formula given by Brown[9] as follows

Carbon stock (t/ha) = (Soil bulk density (g/cm^3) × Soil depth (30 cm) × soil organic carbon (%)) × 100.

Data of all parameters were analysed by ANOVA (analysis of variance) following RBD (randomized block design) using R statistical software. Means were tested using Duncan's test at a significance level of $P \leq 0.005$.

Comparing the biomass contribution of different tree species in agroforestry systems, we found that the contribution of trees to total biomass significantly ($P \leq 0.05$) varied between 62.06 ± 1.26 and 69.43 ± 0.90 Mg ha^{-1} in *T. bellirica* and *E. tereticornis* (Table 1). Significantly ($P \leq 0.05$) highest stem and leaf biomass was recorded in *E. tereticornis* (69.43 ± 0.90 and 2.85 ± 0.08 Mg ha^{-1} respectively). The contribution of other species to biomass production (stem, branch, leaf and root) followed the same trend in terms of per cent contribution. The lowest stem and branch biomass was recorded in *T. bellirica* (48.2 ± 0.40 and 2.41 ± 0.56 Mg ha^{-1} respectively). However, lowest (9.39 ± 0.31 Mg ha^{-1}) root biomass was recorded in *T. ciliate*. Among the different tree components, the highest accumulation of biomass was recorded in stem followed by root, branch and leaf (Figure 1). The highest (80.54%) biomass accumulation was recorded in the stem of *T. ciliate* followed by *S. mukorosi* (79.50%), *P. deltoids* (78.52%), *M. azedarach* (77.92%), *T. bellirica* (77.90%), *A. procera* (77.40%) and *E. tereticornis* (77.13%). The highest branch biomass accumulation was recorded in *P. deltoids* (5.92%), *A. cadamba* (5.49%), *M. azedarach* (4.77%), *T. ciliate* (4.75%), *S. mukorosi* (4.48%) and *E. tereticornis* (4.03%). The highest accumulated leaf biomass was recorded in *E. tereticornis* (3.27%), *A. procera* (2.69%), *P. deltoids* (2.60%) and *A. cadamba* (2.55%). Higher root biomass accumulation was recorded in *A. cadamba* (16.89%), *T. bellirica* (16.12%), *E. tereticornis* (15.56%), *A. procera* (15.07%) and *M. azedarach* (15.05%).

CO_2 mitigation followed the same trend as carbon stock (Table 2). However, total CO_2 mitigation was recorded significantly ($P \leq 0.05$) higher in *E. tereticornis* (160.50 ± 2.55 MgCO$_2$ ha^{-1}), *P. deltoids* (151.27 ± 1.79 MgCO$_2$ ha^{-1}), *T. ciliate* (137.38 ± 2.70 MgCO$_2$ ha^{-1}), *A. cadamba* (130.65 ± 1.95 MgCO$_2$ ha^{-1}), *A. procera* (121.06 ± 2.49 MgCO$_2$ ha^{-1}), *S. mukorosi* (117.85 ± 0.88 MgCO$_2$ ha^{-1}) and *M. azedarach* (115.20 ± 2.74 MgCO$_2$ ha^{-1}) than *T. bellirica* (109.77 ± 1.88 MgCO$_2$ ha^{-1}).

Table 2. Carbon dioxide mitigation (Mg CO_2 ha^{-1}) through different agroforestry tree components

Agroforestry tree species	Stem	Branch	Leaf	Root	Total
P. deltoides	120.05 ± 2.11[a]	8.67 ± 0.63[a]	3.50 ± 0.18[b]	19.05 ± 0.58[bc]	151.27 ± 1.79[b]
T. ciliata	111.28 ± 2.29[b]	6.32 ± 1.14[b]	3.05 ± 0.13[b]	16.73 ± 0.93[c]	137.38 ± 2.70[c]
E. tereticornis	124.30 ± 3.25[a]	6.54 ± 0.70[b]	4.70 ± 0.18[a]	24.96 ± 1.22[a]	160.50 ± 2.55[a]
A. procera	94.09 ± 2.27[d]	5.71 ± 0.32[bc]	2.92 ± 0.21[b]	18.34 ± 0.62[c]	121.06 ± 2.49[e]
M. azedarach	90.64 ± 1.72[de]	5.32 ± 0.57[bc]	2.25 ± 0.12[c]	16.98 ± 0.48[c]	115.20 ± 2.74[ef]
T. bellirica	86.22 ± 2.34[e]	4.15 ± 0.97[c]	1.58 ± 0.26[c]	17.42 ± 0.31[c]	109.77 ± 1.88[f]
A. cadamba	98.51 ± 2.01[c]	7.15 ± 0.46[ab]	3.0 ± 0.26[b]	22.0 ± 1.27[ab]	130.65 ± 1.95[d]
S. mukorosi	93.79 ± 1.20[cd]	5.19 ± 0.52[bc]	1.80 ± 0.13[c]	17.07 ± 2.26[c]	117.85 ± 0.88[e]
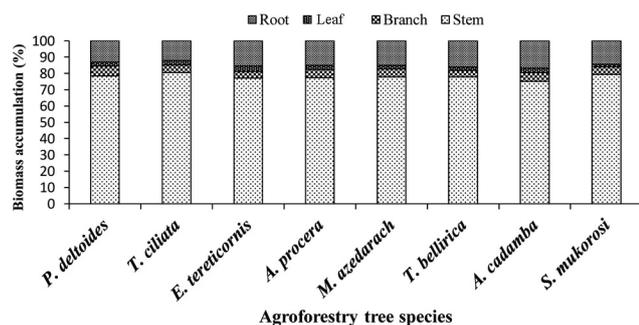
Figure 1. Biomass accumulation in different components of agroforestry tree species.

The highest carbon sequestration was recorded in *E. tereticornis* (31.84%; 45.33 ± 0.60 Mg ha^{-1}), *P. deltoids* (29.52%; 43.84 ± 0.93 Mg ha^{-1}), *T. ciliate* (23.30%; 40.29 ± 1.12 Mg ha^{-1}), *A. cadamba* (15.48%; 36.56 ± 0.68 Mg ha^{-1}), *A. procera* (11.25%; 34.82 ± 0.60 Mg ha^{-1}), *S. mukorosi* (9.34%; 34.08 ± 0.47 Mg ha^{-1}) and *M. azedarach* (4.87%; 32.48 ± 0.72 Mg ha^{-1}) than *T. bellirica* (30.90 ± 0.52 Mg ha^{-1}; Figure 2).

Comparison among different agroforestry systems showed that above-ground wheat biomass significantly ($P \leq 0.05$) ranged from 8.26 ± 0.12 (*A. procera*) to 9.81 ± 0.17 Mg ha^{-1} (*P. deltiodes*) (Table 1). *E. tereticornis* (9.18 ± 0.13 Mg ha^{-1}) also showed significant ($P \leq 0.05$) effect with *A. procera* (8.26 ± 0.12 Mg ha^{-1}). However, below-ground wheat biomass significantly ($P \leq 0.05$) ranged from 1.22 ± 0.02 (*M. azedarach*) to 2.04 ± 0.5 Mg ha^{-1} (*P. deltiodes*) (Table 1).

Above-ground C stock of wheat was recorded significantly ($P \leq 0.05$) higher under *T. bellirica* (3.17 ± 0.09 Mg ha^{-1}) followed by *P. deltoids* (2.96 ± 0.06 Mg ha^{-1}), *S. mukorosi* (2.95 ± 0.03 Mg ha^{-1}), *M. azedarach* (2.85 ± 0.04 Mg ha^{-1}), *E. tereticornis* (2.83 ± 0.08 Mg ha^{-1}), *A. cadamba* (2.74 ± 0.09 Mg ha^{-1}), *T. ciliate* (2.71 ± 0.10 Mg ha^{-1}) and *A. procera* (2.65 ± 0.02 Mg ha^{-1}). However, the highest below-ground C stock was recorded in *P. deltoids* (2.04 ± 0.05 Mg ha^{-1}), followed by *E. tereticornis* (1.66 ± 0.04 Mg ha^{-1}), *T. bellirica* (1.42 ± 0.02 Mg ha^{-1}), *S. mukorosi* (1.41 ± 0.02 Mg ha^{-1}), *A. procera* (1.35 ± 0.02 Mg ha^{-1}), *A. cadamba* (1.26 ± 0.02 Mg ha^{-1}), *T. ciliate* (1.23 ±

0.02 Mg ha^{-1}) and *M. azedarach* (1.22 ± 0.02 Mg ha^{-1}) (Table 3). Total C stock in wheat crop was recorded highest in *T. bellirica* (15.89%), *P. deltoids* (14.48%), *S. mukorosi* (9.44%), *E. tereticornis* (8.08%), *A. cadamba* (2.23%) and *T. ciliate* (1.29%) than *A. procera* (Table 4).

Among agroforestry systems significant ($P \leq 0.05$) maximum soil carbon density was recorded in *E. tereticornis* (37.50 ± 3.52 Mg ha^{-1}), followed by *P. deltoids* (30.75 ± 2.06 Mg ha^{-1}), *M. azedarach* (28.46 ± 1.06 Mg ha^{-1}) and *T. bellirica* (26.56 ± 0.75 Mg ha^{-1}) (Table 4). Soil carbon density in *A. procera* was at par with *T. bellirica* and lowest in *A. cadamba* (24.41 ± 1.26 Mg ha^{-1}).

Production of biomass in different tree components, i.e. stem, branch, leaf, and root depends on various factors such as site quality, growth habit, age, management practices and, most importantly, on how the species interact with the local climate, with the crops and source–sink relationship with trees[10]. The contribution of stem, branch, root and litter biomass was found to be greatly influenced by vegetation type, which influences not only the overall production of biomass but also its partitioning into different components. Our findings are consistent with previous studies, indicating that biomass in agroforestry has significantly increased with morphological variation[11].

In the present study, the pattern of biomass allocation reflected that more biomass was allocated to above-ground components like stem, branch and foliage compared to below-ground parts, which resulted in a higher shoot/root ratio. Tree stem biomass is a function of the volume of stem density; so the volume and biomass estimation is influenced by diameter at breast height (DBH) and height of the stem[12]. Density and spacing of tree species also affect biomass allocation and contribute a greater percentage of total biomass production due to lesser competition and better availability of nutrients[13]. In *P. deltoids*, root distribution pattern decreased with increased radial distance from the tree base at all soil depths. In this species, there was a marginal extension of stump root and lateral root beyond 1.5 m^3 zone of soil volume[14]. Several earlier studies have revealed that most of the root density declines with vertical depth and distance from the tree[15]. The accumulation of more roots in

Table 3. Carbon stock in different agroforestry components (Mg ha^{-1})

| Agroforestry tree species | | Tree species | | | Wheat crop | |
	Stem	Branch	Leaf	Root	SLG	Root
P. deltoides	32.81 ± 0.58[a]	2.37 ± 0.17[a]	0.96 ± 0.05[b]	5.21 ± 0.16[bc]	2.96 ± 0.06[ab]	0.46 ± 0.055[a]
T. ciliata	30.42 ± 0.63[b]	1.73 ± 0.31[b]	0.83 ± 0.03[b]	4.57 ± 0.25[c]	2.71 ± 0.10[c]	0.40 ± 0.013[c]
E. tereticornis	33.95 ± 0.89[a]	1.79 ± 0.19[b]	1.28 ± 0.05[a]	6.82 ± 0.33[a]	2.83 ± 0.08[bc]	0.45 ± 0.014[b]
A. procera	25.72 ± 0.62[d]	1.56 ± 0.09[bc]	0.80 ± 0.06[b]	5.01 ± 0.17[c]	2.65 ± 0.02[c]	0.43 ± 0.008[bc]
M. azedarach	24.77 ± 0.47[de]	1.45 ± 0.16[bc]	0.62 ± 0.03[c]	4.64 ± 0.13[c]	2.85 ± 0.04b[c]	0.42 ± 0.007[c]
T. bellirica	23.55 ± 0.64[e]	1.13 ± 0.27[c]	0.54 ± 0.07[c]	4.76 ± 0.08[c]	3.17 ± 0.09[a]	0.50 ± 0.009[b]
A. cadamba	26.92 ± 0.55[c]	1.95 ± 0.13[ab]	0.82 ± 0.07[b]	6.01 ± 0.35[ab]	2.74 ± 0.09[c]	0.41 ± 0.009[c]
S. mukorosi	25.62 ± 0.33[cd]	1.42 ± 0.14[bc]	0.49 ± 0.04[c]	4.66 ± 0.62[c]	2.95 ± 0.03[b]	0.45 ± 0.013[bc]

Table 4. Total carbon density (Mg ha^{-1}) under different agroforestry systems

Agroforestry system	Tree species	Wheat crop	Soil
P. deltoides	41.33 ± 0.49[b]	3.59 ± 0.05[ab]	30.75 ± 2.06[b]
T. ciliata	37.53 ± 0.74[c]	3.11 ± 0.09[e]	25.93 ± 0.67[de]
E. tereticornis	43.85 ± 0.70[a]	3.34 ± 0.12[cd]	37.50 ± 3.52[a]
A. procera	33.08 ± 0.68[e]	3.07 ± 0.03[e]	26.56 ± 0.75[b]
M. azedarach	31.47 ± 0.75[ef]	3.25 ± 0.03[cde]	28.46 ± 1.06[c]
T. bellirica	30.0 ± 0.51[f]	3.65 ± 0.09[a]	26.53 ± 1.14[d]
A. cadamba	35.70 ± 0.53[d]	3.14 ± 0.11[de]	24.41 ± 1.26[f]
S. mukorosi	32.20 ± 0.24[e]	3.39 ± 0.02[bc]	25.78 ± 0.75[de]
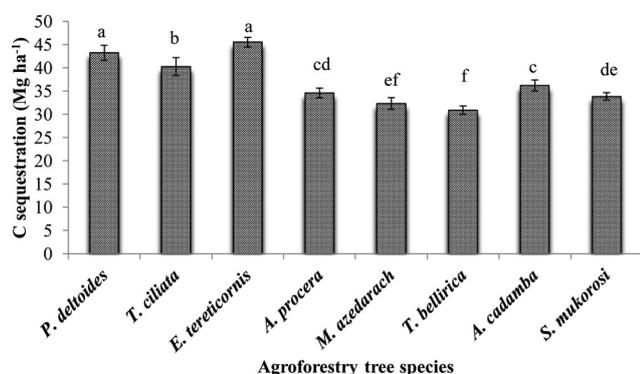
Figure 2. Carbon sequestration through different agroforestry tree species.

the upper soil layer provides access to the moisture and nutrients available in the topsoil. Similarly, in the present study, more organic carbon was reported in the 0–30 cm soil layer.

Higher wheat biomass was recorded in *P. deltoids* and *E. tereticornis*-based agroforestry systems. This might be due to higher accumulation of carbon in these agroforestry systems, resulting in better growth of understorey crops. On the other hand, decreasing crop biomass in other agroforestry systems might be due to competition between trees and crops for resource sharing, i.e. light, water and nutrients, resulting in a decrease in the accumulation of dry matter[16]. Considerable amount of carbon

is allocated in *C. illinoinensis*-based agroforestry systems than other agroforestry systems. Biomass differences in various agroforestry systems might be due to a variety of factors, such as growth conditions, site quality, age, density, structure and management practices, and their association with tree species.

Carbon stocks depend on tree density and different components of various species such as stem, branch, leaf, etc. In the present study, carbon content in the stem of the *Dalbergia sissoo* was higher than its leaves and branches[17]. Studies have also suggested that stem wood biomass accounted for 49.7–51.7% of the total biomass. The concentration of carbon in biomass is a critical indicator for the determination of carbon sequestration in any plant.

The highest contribution of carbon sequestration was shown by stump roots > lateral roots > fine roots. The long-lived carbon remaining in the tree after its life cycle is resistant to microbial attacks during decomposition due to higher lignin content. Thus, it sequesters carbon for a longer time after felling, compared to the carbon stored in leaf and branch biomass[18]. The stem contributes maximum to total carbon sequestration in all tree species among the sub-components of a tree. The contribution of total carbon stock of different components of the tree-based agroforestry system is in the order of tree stem > branch > root > litter[19].

CO_2 mitigation of plants is directly related to biomass of the tree. Maximum biomass production in tree components is responsible for mitigating more CO_2 from the atmosphere. In the present study, higher CO_2 mitigation was recorded in the *E. tereticornis* and *P. deltoids* agroforestry systems. This might be due to more biomass and carbon stock accumulation in these agroforestry systems. Previous studies also showed that higher mitigation value of pecan nut + wheat system and pecan nut + lentil system is attributed to more biomass and carbon stock in the agroforestry system compared to sole agriculture system[20]. Various factors such as species, site, age and silvicultural practices may favour tree growth and productivity which promote CO_2 sequestration as well as C conservation. Agroforestry practices in many parts of the

Himalayan region provide an important environmental service through mitigation of atmospheric CO_2 (ref. 21).

Considering the components of different tree species, for long-term storage and coal substitution, carbon sequestration was significantly ($P \leq 0.05$) higher in the *E. teriticornis* and *P. deltoids* agroforestry systems. This might be due to higher biomass accumulation in these tree species. In the tree components, stem can sequester carbon for a long time after felling compared to carbon stored in the leaf and branch biomass[22]. However, carbon sequestration potential of above- and below-ground vegetation is highly varied in the agroforestry systems, which has drawn more attention to adaptation and mitigation of climate change[23]. It was reported that agroforestry can store carbon in the range 12–228 Mg ha^{-1}, which varies with location, age, density and plantation, as well as the quality of stock planting[24].

Soil carbon stock was estimated to be higher in *E. teriticornis* and *P. deltoids* agroforestry systems. This might be due to the fact that soil organic carbon (SOC) sequestration relies primarily on the processes of soil C input and soil stabilization. Plant root and rhizospheric inputs contribute significantly to SOC[25]. However, the relation between quality of plant litter and SOC is not yet well understood[26]. Generally, higher SOC pools in agroforestry systems can be achieved by increasing the amount of biomass C returned to the soil and enhancing soil organic matter[27]. Whereas, the formation and stabilization of SOC might be influenced more by the amount of litter input and its interaction with the soil matrix than the litter quality[28]. Carbon sequestration in agroforestry systems also improved by increasing the proportion of stabilized SOC fraction in deeper soil horizons[29]. This might be due to the decomposition of dead tree roots, root exudates and associated microorganisms[30]. Functionally important tree species, i.e. those with deep and extensive root systems that increase C input into the soil, may have a high potential to increase SOC sequestration in agroforestry systems[31]. Broadleaf trees have a more deep-anchored root system, i.e. higher ratios of root biomass/above-ground biomass, and can therefore produce higher SOC inputs from roots[32].

In the present study, biomass production and carbon stock of vegetation differed in agroforestry systems. All the species used in the study showed great potential for C sequestration and CO_2 mitigation. In tree stem biomass, C stock and CO_2 mitigation were considerably higher compared to root and followed the order: stem > root > branch > leaf. Trees contribute more biomass and consequently store more carbon, but crops in agroforestry still make a major contribution to the production of biomass and carbon stock. Compared to other agroforestry systems, soil carbon density was higher in the *E. tereticornis*-based agroforestry system due to the addition of more litter to the soil. Therefore, the present study indicates that in this evolving climate change scenario, agroforestry systems are more appropriate for biomass and carbon storage.

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BDNF protects photoreceptors from light-induced oxidative stress through upregulating CERKL *in vitro*

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Brain-derived neurotrophic factor (BDNF) protects the retina from light-induced injury. In this study, white light suppressed the cell viability of 661W photoreceptor cells in a time- and intensity-dependent manner, decreased the mRNA and protein levels of ceramide kinase-like (CERKL), but increased the reactive oxygen species (ROS) content in 24 h. Decrease in ROS content and increase in CERKL level were detected after BDNF treatment. BDNF also attenuated the light-induced ROS accumulation, as well as cell viability and CERKL suppression. Thus, strong light causes CERKL suppression, ROS accumulation and the consequent attenuation of photoreceptor viability, while BDNF protects it from such injuries through upregulating CERKL expression and downregulating ROS accumulation.

RETINAL degeneration, such as retinitis pigmentosa and age-related macular degeneration, is a retinopathy typically characterized by pathological loss of highly differentiated cells, especially photoreceptor cells, which may lead to irreversible visual impairment and even blindness[1]. Although the incidence is high and keeps rising, there is currently no effective treatment for retinal degeneration.

A wide variety of causes have been proved to attribute to retinal degeneration, among which retinal light injury is regarded as an important factor. In the retina, prolonged or high-intensity exposure to visible light results in apoptosis of photoreceptor cells, and development of intracellular reactive oxygen species (ROS) and lipid peroxidation[2]. The accumulation of ROS in the photoreceptors is one of the major pathophysiological changes in the light-induced retinal degeneration[3–5], which further leads to apoptosis of photoreceptor cells and eventually blindness.

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