the combined effects from a variety of factors like the type of curing, diameter of the fibre and environmental/exposure conditions initiate their deterioration[10]. In the present study, though the coir fibres facilitate microbial activity, these microorganisms are expected to depend on the substrates from the wastewater for their growth rather than the coir material. However, an adaptive shift in substrate dependence should be expected when these reactors are subjected to a repeated cycle of closure and re-use. A preliminary assessment done on reactors that were operated continuously for a period of one year showed only a marginal reduction in the dry weight (less than 2%). On clogging, the stiffness of the fibres and porous matrix of non-woven coir geotextiles provided enough space for the wastewater to flow and prevented any such problems in low-density filters. However, for higher fibre packing (above 80 kg/m^3), continuous operation of the filters required frequent cleaning due to the formation of biological flocs in the inlet region of the reactors.

The utility of coir geotextiles in the design of biofilters for the treatment of wastewater, loaded with biodegradable matter, has been successfully established in this communication. This would certainly result in expanding the engineering application for coir geotextiles, which are presently used more extensively in geotechnical engineering and water management projects. The laboratory results obtained from this study have given the necessary information to design and evaluate the long-term performance of a field-scale, reactive sewer unit. Future work must look into coir geotextile filters that could be directly attached along the sewer lines to make the wastewater treatment operations more energy-efficient.

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Prioritizing land-management options for carbon sequestration potential

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Global warming is inevitable. Therefore, the need is to develop strategies to reduce the greenhouse gases from the atmosphere. Carbon sequestration through biomass seems to be a cheap and viable option. There are several land-use options which can sequester carbon. Their potential of locking carbon differs not only with the type of species, but also with the agroclimatic zones. Hence, location-specific land-use systems need to be prioritized taking both carbon sequestration potential and socio-economic needs into account. It was found that in the terai zone of West Bengal, fallow land and agricultural field sequester 5.86% and 4.73% carbon respectively, compared to the natural forest of *Shorea robusta*. However, agroforestry systems, viz. tea garden and agrihorticulture contributed 24.24% and 9.09% carbon respectively. The agrihorticulture system while sequestering carbon also provides agricultural crops and other economic gains, including carbon credits, and hence seems to be the best option. The potential of carbon storage of tree + crop-based system can be further increased using improved planting materials of perennial components.

Keywords: Agrihorticulture, carbon sequestration, global warming, greenhouse gases.

THE implications of increased concentration of CO_2 for climate and health of the global environment are topics of intense scientific, social and political concern. In contrast to economic globalization, no country can be left out of environmental globalization, as its consequences will sooner

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or later reach all. The direct solution to the problem is reducing CO_2 emission. However, the costs of this approach may be prohibitive for industrialized countries due to its adverse effect on their production. Ability of the terrestrial biosphere to sequester and store atmospheric CO_2 has been recognized as an effective and low-cost method of offsetting carbon emissions. Carbon sequestration potential differs with the kind of land use. It is a proven fact that forest ecosystems are the best way to sequester carbon. However, considering the huge human population and degraded areas in developing countries like India, the immediate need is to provide food and under such circumstances, much of the land cannot be spared for increase in forest cover. Also, landholding of most of the farmers in developing countries is less and they cannot spare land to permanent tree cover, as it will not provide immediate benefit. Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of global climate change[1]. Therefore, the need is to assess the potential of different land-management options which can fulfil both environmental and economic goals. Discussions are going on to find a suitable land-use system which, on the one hand, will fulfil our requirements of food, fodder and timber and on the other, has environmental benefits. Carbon sequestration depends upon biomass production capacity, which in turn depends upon interaction between edaphic, climatic and topographic factors of an area. Hence results obtained at one place may not be applicable to another. Therefore, region-based potential of different land uses needs to be worked out. Thus the present study was aimed at assessing the appropriateness of tree-based land-use systems as an alternative to continuous cropping and permanent grasslands. The assessment is based on the ability of the system to sequester and store carbon.

The study site is a terai zone (foothill plains of Himalayas) in West Bengal, which lies between 26°30′–26°56′N lat. and 88°7′–89°53′E long. It spans an area of 12,015 km^2, covering the districts of Cooch Behar and Jalpaiguri. The land-use pattern of this region can be classified into five broad categories. About 50% of the land is net-sown and 22% is under non-agricultural uses. Forests occupy a little over 14% mainly confined to the Jalpaiguri District and the Siliguri sub-division of Darjeeling District. Orchards and plantation crops occupy about 9% of the land, tea is the most important commercial plantation crop dominantly grown in Jalpaiguri District. The area under barren land is about 4% and 1% falls under fallow and cultivable waste[2]. The climate of terai zone is sub-tropical humid in nature. Based on the old system of classification, soils of the study site can be broadly classified into Teesta alluvium, terai and brown forest soils. However, according to the modern system of classification, soils are an association of Dystrochrepts and Haplaquepts of the order Inceptisols and Udifluvent/Udorthent/Ustorthent of the order Entisol[2].

Seven land uses under vogue, namely fallow land, agriculture field, tea garden, agrihorticulture agroforestry system, plantation of *Dalbergia sissoo*, plantation of *Terminalia arjuna* and natural forest of *Shorea robusta* were chosen for comparing their carbon sequestration potentials. Details of the land-use system are given in Table 1. Plot size of 1 × 1 m for grasses and 10 × 10 m for tree-based land-use systems was taken for observations. For each land use, five replications were taken. In each plot above ground biomass was estimated using non-destructive method and its biomass partitioning was done. Stem biomass of all the trees in the sample plot of 10 × 10 m was enumerated. The diameter at breast height (dbh) was measured with a caliper and height with Ravi's multimeter. Form factor was calculated with Spiegel relaskope to find out the tree volume using the formula given by Pressler[3] and Bitterlich[4]:

$$f = 2h_1/3h,$$

where f is the form factor, h_1 the height at which diameter is half dbh and h is the total height.

Volume V was calculated using the Pressler formula[3]

$$V = f \times h \times g,$$

where f is the form factor, h the total height and g the basal area calculated as $g = \pi r^2$ or $(\text{dbh}/2)^2$, where r is the radius.

Specific gravity was estimated taking the stem cores, which was further used to determine biomass of the stem using the maximum moisture method.

Table 1. Details of land-use systems selected

Land-use system	Plot size (m)	No. of trees (ha^{-1})	Initial tree spacing (m)	Year of planting
Fallow land/uncultivated land	1 × 1	–	–	The land has not been cultivated for the last 15 years
Agricultural field	1 × 1	–	–	–
Tea garden	10 × 10	400	6 × 6	1996
Agrihorticulture agroforestry system	10 × 10	400	8 × 8	1996
Pure plantation of *Dalbergia sissoo*	10 × 10	1800	1.5 × 1.5	1997
Pure plantation of *Terminalia arjuna*	10 × 10	2200	1.5 × 1.5	1997
Natural forest of *Shorea robusta*	10 × 10	700	–	1976

$$G_f = \frac{1}{\frac{M_n - M_0}{M_0} + \frac{1}{G_{So}}}, \quad (1)$$

where G_f is the specific gravity based on gross volume, M_n the weight of saturated volume sample, M_o the weight of oven-dried sample and G_{So} the average density of wood substances equal to 1.53.

Thus, the weight of wood was estimated using the following equation:

$$\text{Biomass} = \text{specific gravity} \times \text{volume}. \quad (2)$$

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized on the basis of basal diameter into three groups, viz. <6 cm, 6–10 cm and >10 cm. Fresh weight of two branches from each size group was recorded separately. Dry weight of branches was estimated using the following equation[5]

$$B_{dwi} = B_{fwi}/1 + M_{cdbi,} \quad (3)$$

where B_{dwi} is the oven dry weight of branches, B_{fwi} the fresh/green weight of branches and M_{cdbi} the moisture content of branches on dry weight basis.

Total branch biomass (fresh/dry) per sample tree was determined as follows

$$B_{bt} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \sum_{i=1}^{n} n_i bw_i, \quad (4)$$

where B_{bt} is the branch biomass (fresh/dry) per tree, n_i the number of branches in the ith branch group, bw_i the average weight of branches in the ith group and $i = 1, 2, 3, \ldots$ the branch groups.

Leaves from five branches of individual trees were removed. Five trees per plot were taken for observation. The leaves were weighed and oven-dried separately[5] to a constant weight at 80 ± 5°C. The average leaf biomass was then arrived at by multiplying the average biomass of the leaves per branch with the number of branches in a single tree and the number of trees in a plot. Crop biomass was estimated using 1 m × 1 m quadrates. All the plants occurring within the borders of the quadrate were cut at ground level, weighed, sub-sampled and oven-dried at 65 ± 5°C to a constant weight. In a similar manner, grass/herb/shrub biomass was also estimated.

To arrive at the amount of sequestered carbon content of different land uses, the biomass was converted into carbon by multiplying with a factor of 0.45, as used by Woomer[6]. The data obtained were subjected to two-way ANOVA following Gomez and Gomez[7], using the package 'INDOSTAT'.

Estimates of biomass accumulation under different land uses and their corresponding carbon stocks are given in Figures 1 and 2. The total biomass (t/ha) accumulated at the time of observation was maximum in natural forest of *S. robusta* (NFSR), followed by plantation of *D. sissoo* (PDS), tea garden (TG), plantation of *T. arjuna* (PTA), mango-based agrihorticulture agroforestry system (AHAF), agricultural field (AF) and fallow land (FL) (Figure 1). However, while considering the rate of accumulation of biomass per unit area and per unit time with reference to total biomass accumulated, land use systems based on annual crops exceeded the values compared to those having perennials as dominant components (Figure 2). Taking the amount of biomass accumulated per year, natural forest had an edge over the rest of the land uses followed by PDS, TG, PTA and least in FL. Converting biomass into carbon stored in all the land uses, the trend remained almost the same. Maximum carbon storage was in natural forest (891.02) followed by PDS (176.92), TG (126.66), PTA (113.16), TG (14.62), AF (4.87) and least in FL (0.59) (Figure 1). The rate of carbon sequestered per unit area per unit time was highest in natural forest, being 29.7 t/ha/yr followed by 19.66 in PDS, 12.66 in TG and PTA, 4.87 in AF, 2.9 in AHAF and 0.59 in FL (Figure 2).

Perennial components in each land use were partitioned into stem, branch and leaf. Stem biomass contributed

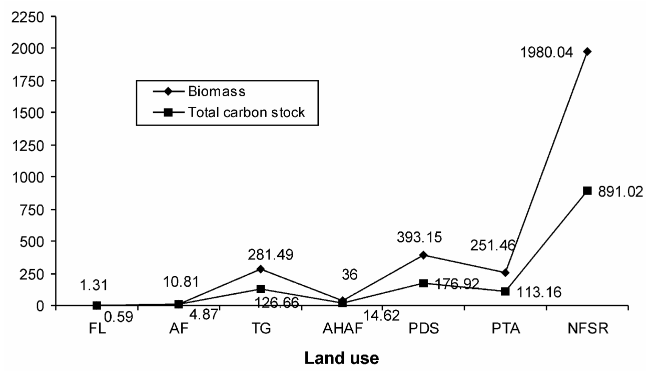

Figure 1. Biomass and carbon stock (t/ha) in different land uses.

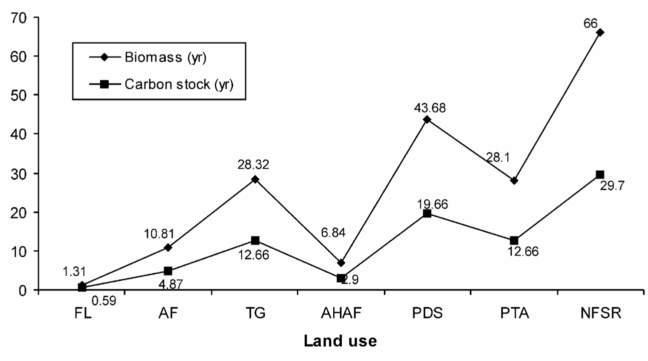

Figure 2. Biomass and carbon increment (t/ha/yr) under different land uses.

Table 2. Partitioning of above ground biomass (t/ha) under different land uses

Component	FL	AF	TG	AHAF	PDS	PTA	NFSR
Stem	0.00	0.00	254.81	13.77	287.28	97.70	1080.48
Branch	0.00	0.00	10.74	14.82	103.71	149.09	892.25
Leaf	0.00	0.00	0.65	3.86	2.17	4.67	5.56
Whole tree	0.00	0.00	258.80	32.45	393.15	251.46	1978.29
Crop/associated crop	0.00	10.81	15.35	3.55	0.00	0.00	0.00
Grass/herb/shrub	1.31	0.00	0.00	0.00	0.00	0.00	1.75
Total	1.31	10.81	281.49	36.00	393.15	251.46	1980.04
$CD_{(p = 0.05)}$	0.01	1.01	52.55	2.43	118.72	23.57	43.24

Table 3. Rate of biomass (t/ha/yr) accumulation under different land uses

Component	FL	AF	TG	AHAF	PDS	PTA	NFSR
Stem	0.00	0.00	25.80	1.38	31.92	10.86	36.02
Branch	0.00	0.00	1.07	1.48	11.52	16.56	29.74
Leaf	0.00	0.00	0.07	0.39	0.24	0.52	0.19
Whole tree	0.00	0.00	26.61	3.24	43.68	27.94	65.94
Crop/associated crop	0.00	10.81	1.53	3.56	0.00	0.00	0.00
Grass/herb/shrub	1.31	0.00	0.00	0.00	0.00	0.00	0.06
Total	1.31	10.81	28.15	6.81	43.68	28.10	66.00
$CD_{(p = 0.05)}$	0.01	1.01	4.96	0.26	13.19	2.62	1.44

Table 4. Above ground carbon stock (t/ha) under different land uses

Component	FL	AF	TG	AHAF	PDS	PTA	NFSR
Stem	0.00	0.00	114.64	6.20	129.27	43.96	486.22
Branch	0.00	0.00	4.83	6.67	46.67	67.09	401.51
Leaf	0.00	0.00	0.29	0.38	0.98	2.10	2.50
Whole tree	0.00	0.00	119.76	13.01	176.92	113.16	890.23
Crop/associated crop	0.00	4.87	6.90	1.60	0.00	0.00	0.00
Grass/herb/shrub	0.59	0.00	0.00	0.00	0.00	0.00	0.79
Total	0.59	4.87	126.66	14.62	176.92	113.16	891.02
$CD_{(p = 0.05)}$	0.005	0.45	22.78	0.97	53.43	10.61	19.46

the most followed by branch and leaves in all the land uses studied, except agrihorticulture agroforestry system and pure plantation of *T. arjuna*, where branch biomass exceeded stem biomass (Table 2). Rate of accumulation of biomass in different components was also calculated (Table 3). Maximum rate of biomass accumulation was in natural forest followed by plantation of *D. sissoo* and least in fallow land. Amongst biomass contributing components in land use systems, maximum rate of biomass accumulation was in the stem followed by associated crops. In land-use systems which did not have any crops, their branch biomass ranked second. However, in plantation of *T. arjuna* and agrihorticulture land-use systems, the rate of biomass accumulation was more in the branch than stem. Carbon accumulation in different plant parts and rate of carbon accumulation per year is given in Tables 4 and 5 respectively. It was found that the carbon sequestration was highest in the stem followed by the branch, except in case of PTA and AHAF where carbon sequestration was more in the branch and less in the stem. In tea garden, associated crop ranked second in sequestering carbon after stem.

Moura-Costa[8] compared carbon sequestration potential of plantation, agroforestry and rainforest up to 20–30 years. He reported that plantation of fast-growing species sequestered 100–200 t/ha of carbon, agroforestry sequestered 90–150 t/ha and maximum amount of carbon sequestered was 300–400 t/ha in rainforest. Winjum *et al.*[9] estimated the amount of C sequestered per unit area for five major forestry practices: reforestation (artificial regeneration), afforestation (similar to reforestation, but done on land that has not supported forests for 50 years), natural regeneration, silviculture and agroforestry. According to them, median tropical forest carbon (t C ha^{-1}) was highest for natural reforestation (119) followed by agroforestry (95), reforestation (65), silviculture (34) and afforestation (29). Houghton *et al.*[10] considered three methods of forestry practices for C sequestration: plantation, agroforestry and protection/regeneration. In Asia, protection sequestered maximum C (7 Gt C), followed by

Table 5. Rate of accumulation of above ground carbon stock (t/ha/yr) under different land uses

Component	FL	AF	TG	AHAF	PDS	PTA	NFSR
Stem	0.00	0.00	11.47	0.62	14.36	4.90	16.21
Branch	0.00	0.00	0.48	0.67	5.19	7.45	13.38
Leaf	0.00	0.00	0.03	0.02	0.11	0.23	0.08
Whole tree	0.00	0.00	11.98	1.30	19.66	13.66	29.70
Crop/associated crop	0.00	4.87	0.68	1.60	0.00	0.00	0.00
Grass/herb/shrub	0.59	0.00	0.00	0.00	0.00	0.00	0.03
Total	0.59	4.93	12.66	2.90	19.66	13.66	29.75
$CD_{(p = 0.05)}$	0.005	0.50	2.28	0.11	5.93	2.10	0.68

plantation (3) and agroforestry (1). In Latin America, carbon sequestration was maximum in agroforestry (16 Gt C) followed by plantation (9) and protection (7). In Africa, plantation sequestered maximum amount of carbon (15 Gt C) followed by agroforestry (6) and protection (3). Carbon storage is intricately linked with site quality, nature of land use, choice of species and other crop management practices adopted[11]. Higher biomass and hence more carbon stock in natural forest is because of the efficient utilization of space due to the presence of grasses, shrubs and trees on the same patch of land; higher SOC also leads to increased rate of plant growth. In general, stem contributed more than branch and least contribution was made by the leaf except in case of agri-horticulture agroforestry system and plantation of *T. arjuna*, where branch contributed more than stem. This is because of the fact that *Mangifera indica* is trained and pruned in such a way that the crown surface area increases, which leads to more fruiting and hence more branch biomass and restricted stem dimension. In case of pure plantation of *T. arjuna,* branch biomass was more because of grazing pressure in the initial stages of plantation, which had led to profuse side branches.

Carbon management has assumed great significance for climate change mitigation. Prioritizing land-use options for storing carbon is urgently required. It is concluded from the present study that carbon sequestration potential of fallow land and agriculture field is only 5.86% and 4.73% respectively, compared to natural forest of *S. robusta*. However, agroforestry systems, viz. tea garden and agri-horticulture contributed 24.24% and 9.09% carbon respectively, whereas pure plantation of *D. sissoo* and *T. arjuna* contributed 31.59% and 23.93% carbon respectively, compared to natural forest of *S. robusta*. Though natural forest and pure plantation sequester more carbon and hence are better options for reducing atmospheric carbon, they cannot be extended to large areas due to population pressure and high demand of land for agricultural purposes. Therefore, agroforestry system seems to be the best alternative to minimize atmospheric carbon and simultaneously harness the opportunity for biodiversity conservation and economic benefits to the society. Ruark *et al.*[12] have also concluded that agroforestry is an important strategy in sequestration of carbon. Agroforestry can also reduce poverty of low-income farmers through earning carbon credits under CDM (clean development mechanism)[13]. Average carbon storage by agroforestry practices had been estimated to be 9, 21 and 50 Mg C ha^{-1} in semiarid, sub-humid and humid regions respectively[14], which is high compared to the present study. Thus more diverse agroforestry systems like homegardens need to be practised. Further, improved planting materials and standardizing the number of trees per unit area with appropriate management practices will help in increasing the carbon storage in lesser time on the same land management unit. In terai zone of Uttarakhand, improved clones of poplar were able to give a high productivity of 50 $m^3 ha^{-1} yr^{-1}$ in short span of 8 years[15] and Eucalyptus clones produced 20–25 $m^3 ha^{-1} yr^{-1}$ under unirrigated conditions in Andhra Pradesh[16], thus sequestering more carbon per unit area per unit time. Associating nitrogen-fixing trees in agroforestry system will help in improving the production and sustainability of the system. This is particularly necessary because more then 50% of the country's land is degraded. However, certain agroforestry systems like ruminant-based agrosilvopastoral systems and rice paddy agrosilvicultural systems which are source of CH_4, need to be avoided[17].

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Natural anthocyanins as photosensitizers for dye-sensitized solar devices

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Different natural pigments containing anthocyanins extracted from tropical flowers were studied as possible sensitizers for TiO_2 by assembling dye-sensitized solar cells (DSCs). Photocurrent densities ranging from 1.1 to 5.4 mA cm^{-2} were obtained with photovoltages ranging from 390 to 410 mV. The overall efficiency and fill factor of these cells varied from 0.2 to 1.1 and 53 to 64 respectively. Among the flower pigments studied, the extract from *Hibiscus surattensis*-HST (cultivated species/colour of the flower: magenta) gave the best photosensitized effect, which can be used as an environment-friendly, low-cost alternative system, especially for educational purposes.

Keywords: Dyes, natural pigments, solar cells, tropical flowers.

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DYE-sensitized solar cells (DSCs) have attracted much attention as low-cost photovoltaic cells and have become a rapidly expanding field with potential applications, especially after the discovery of an efficient photovoltaic cell by O'Regan and Grätzel[1,2]. In this context, although highly efficient cells have been shown to operate with power conversions up to 10% using nanoporous TiO_2 electrodes sensitized with ruthenium complexes, there remains the need for alternative photosensitizers for use with TiO_2-based photovoltaic devices, especially due to the high cost of ruthenium complexes and the long-term unavailability of these noble metals. Therefore, investigation of low cost, readily available dyes as efficient sensitizers for DSCs still remains a scientific challenge[3–13]. In this context, application of naturally occurring pigments such as anthocyanins, carotenoids and chlorophylls for DSCs has several advantages over rare metal complexes and other organic dyes, such as readily availability, easy extraction into cheap organic solvents, can be applied without further purification, is environment-friendly and considerably reduces the cost of the devices. Numerous efforts have been done by several research groups all over the world to utilize these natural dyes as sensitizers in these devices[12–16]. In this context, among the natural dyes, anthocyanins are a group of naturally occurring phenolic compounds responsible for the colour of many flowers, fruits (particularly in berries) and vegetables[17,18]. They are glycosylated polyhydroxy or polymethoxy derivatives of 2-phenylbenzopyrylium or flavylium salts, which consist of three six-membered rings (Figure 1) and usually the glycosylation occurs at 3, 5 and 7 positions. These important floral pigments give rise to a wide range of flower colours, from orange to blue[18]. The most common anthocyanidins found in flowers are pelargonidin (orange), cyanidin (orange-red), peonidin (orange-red), delphinidin (blue-red), petunidin (blue-red) and malvidin (blue-red; Figure 1)[17–19].

In this study we have extracted anthocyanine pigments from several locally available flowers and especially from one of the endemic plants, *Rhododendron arboretum zeylanicum*-RAZ (locally called maha rathmal; colour of the flower: red). The other pigments included *Sesbania grandiflora* Scarlet – SGS (locally called as rathu kathuru murunga; colour of the flower: red), *Hibiscus rosasinensis* – HRS (locally called pokuru wada; colour of the flower: deep red), *Hibiscus surattensis* – HST (cultivated species; colour of the flower: magenta), *Nerium oleander* – NRO (locally called kaneru; colour of the flower: red), *Ixora macrothyrsa* – IMT (locally called rath mal; colour of the flower: orange-red). We studied their photo-responses as sensitizers for DSCs.

Petals of flowers chosen were cut into small pieces and extracted into ethanol (Fluka, 96% (v/v)), keeping them overnight. Then residual parts were removed by filtration and the filtrate was washed with hexane several times to remove any oil or chlorophyll present. The ethanol frac-