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SOIL CHARACTERISTICS AND CARBON SEQUESTRATION POTENTIALS OF VEGETATION IN DEGRADED HILLS OF CHITTAGONG, BANGLADESH

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ABSTRACT

The impacts of tree and horticultural plantations, and grassland on soil characteristics in the degraded hills of Chittagong District, Bangladesh are reported on this paper. The carbon sequestration potential and the present value of carbon revenue flow were also estimated for the degraded hills of Chittagong using *A. auriculiformis* plantations for the purpose. The results showed that the change of land use from degraded hill to vegetation cover had altered the physico-chemical characteristics of soil in the study area. The organic carbon concentration and storage under vegetated land uses were significantly ($p < 0{\cdot}05$) higher than those in the degraded hill areas. The results also showed that about 17 million megagram carbon (MgC) could be sequestered in the degraded hill areas of Chittagong District by planting *A. auriculiformis* trees in a 15-year rotation. The present value of revenue flow generated by this sequestration at the current international market carbon price and assuming a realistic market interest rate could be as high as US$ 326 million. The net present value of the revenue stream is expected to be positive. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: carbon sequestration; Chittagong District; degraded hills; present value of carbon revenue; soil characteristics; vegetated land uses; Bangladesh

INTRODUCTION

Physiographically Bangladesh is divided into hills, terraces and floodplains. The hills are situated in the north, southeast and northeastern parts of the Country covering an area of about 1·73 million ha (mha), i.e. 12 per cent of total land area of the Country. The Chittagong District and Chittagong Hill Tracts (CHTs), situated in the southeast of the Country, have the highest concentration of hills covering 1·29 and 0·27 mha, respectively (Brammer, 2002). In Chittagong, there are two major hill ranges, *viz.* the Raozan–Rangunia and the Hathazari–Fatikchari (Rashid, 1991). The Hathazari–Fatikchari hill range covers four sub-districts of Chittagong, *viz.* Hathazari, Sitakund, Mirersharai and Fatikchari. This hill range, especially in the Hathazari region, was once covered with dense tropical forests and has suffered from severe deforestation over the last 50 years. At present most parts of the hill range are covered with grasses, a few shrubs and scattered trees.

The soils of the Hathazari–Fatikchari range, fall into the Barkal Series and are moderately well to very well drained, acidic in reaction and with low organic matter content (Hassan, 1999). They generally have a low level of fertility. Gradual loss of tree cover over the years from this hill range, particularly in the Hathazari sub-District, has caused severe soil erosion and the loss of nutrient rich topsoil. Thus, the hills in this range have become unsuitable for agriculture, the main form of land use in Bangladesh, and forestry has been considered the most suitable land use (Pasha, 2003).

Since the early-1990s some parts of the degraded hills, especially in the Hathazari–Fatikchari range (notably in Hatahzari sub-District), have been afforested with trees, and planted with horticultural or fodder crops. There monoculture plantations especially of *Acacia auriculiformis*[1] and *Eucalyptus camaldulensis*, and mixed plots of horticultural crops, i.e. fruit trees, in steep and moderately steep hill slopes, and fodder grasses in hill marsh areas are the three most common forms of vegetated land use. In this paper, these three vegetated land uses are referred as tree plantation, horticulture and grassland, respectively.

There is abundant evidence from soil science and forestry literature that vegetated and forested land uses around the globe have impacts on soil characteristics. Singh *et al.* (2004) reported that plantations of *Albizia procera*, *A.*

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[1]To the best of our knowledge, the actual area covered *by A. auriculiformis* or other plantations in Chittagong or in Bangladesh is not known.

lebbeck and *Tectona grandis* in a dry tropical environment in India had improved the soil qualities. Dutta and Agarwal (2002) showed that in Madhya Pradesh, India the physio-chemical characteristics of soil under tree plantations had improved considerably compared with bare overburden mine spoil. Shaifullah *et al.* (2009) reported that moisture content, organic carbon, pH and total nitrogen in soil under *Sonneratia apetala* plantations in the coastal area of Bangladesh were significantly higher than those in adjacent barren lands. Jha *et al.* (2001) found that forestry vegetation improved organic matter status of soil in India, and Miah *et al.* (2001) found the same for the hill forests of Bangladesh. Marcos *et al.* (2007) demonstrated that total organic matter accumulation increased with the age of *Pinus sylvestris* in León Province of Spain. Haque and Karmakar (2009) reported the same for plantations in the hilly area of Chittagong District, Bangladesh. Examining these studies, it is realistic to assume that vegetated land uses have impacts on soil characteristics. Scientific literature analysing the effects of tree plantation together with grassland and horticultural land uses on the physico-chemical properties of degraded hilly soil in Chittagong District of Bangladesh is limited.

Unsustainable uses of hills such as intensive shifting cultivation and human settlement from over populated lowland districts and over cutting and illegal removal of trees, followed by artificial regeneration with fast growing species has occurred in Chittagong and Cox's Bazar Districts. Governmental policies towards the sustainable use of degraded hills and upland watersheds of CHTs and Chittagong in particular, and in the whole of Bangladesh in general, have either been indecisive or ineffective. Previous literature has discussed options such as less intensive shifting cultivation (Borggaard *et al.*, 2003), agro-forestry (Hassan and Alam, 2006) and horticulture as the suitable land uses for the upland hills. However, only a few studies have been conducted and these suggest tree plantation for carbon sequestration as a suitable land use on the upland hills. Miah *et al.* (2004) reported the potential for carbon sequestration in tree plantations of Chittagong District. Shin *et al.* (2007 and 2008) and Miah and Shin (2009) discussed the carbon sequestration potential of the forestry sector in Bangladesh. However, none of these studies has focused on degraded hills, or has estimated the potential for carbon sequestration and the resultant revenue flow through tree plantations.

This paper first analyses the effects of three vegetated land uses, *viz.* tree plantation, horticulture and grassland on the soil properties in the degraded hills of Chittagong District. Then using the carbon storage in the degraded hill as the base line, the paper measures the mean annual carbon accumulation rates on the ground, i.e. in soil and litter together, for the three aforementioned land uses. Finally, the paper estimates the carbon sequestration potential and the revenue flow of that sequestration under tree plantations in the degraded hills of Chittagong District. This estimation is done using an example of 15-year rotation *A. auriculiformis* plantations in which the carbon credits are measured when the trees are ready to be sold in the market at the end of every 5 years throughout the rotation.

MATERIALS AND METHODS

Description of Soil Sampling Sites

The soil samples for the three different land uses mentioned earlier and a degraded hill were collected from Hathazari sub-District, part of the Hathazari-Fatikchari hill range. The Hathazari sub-District lies between 22°24′02" and 22°40′06" N latitude and 91°43′28" and 91°55′21" E longitude (Figure 1). The key features of the land uses and the degraded hill are given below:

(i) **Tree plantation**: This site contained 6-year old *Acacia auriculiformis* plantation established as a monoculture on land with a 45 per cent slope. The plantation was privately raised on land leased from the government.[2] The canopy coverage of the plantation was about 60 per cent with a stem density of 1450 trees per ha. The average height and diameter at breast height (dbh) were 3·60 and 8·2 cm, respectively. The tree plantation had an unevenly distributed undergrowth cover, which mainly composed of *Clerodendrum viscosum* (**bhat**), *Mimosa pudica* (**lajjabati**), *Caealpinia cristael* (**kootumkanta**), *Hyptic sauveolens* (**tokma**), *Eupatorium odoratum* (**assamlata**), *Mikania cordata* (**tarakanta**), and *Melastoma melabatricum* (**tea indicator**) with a few vines and creepers. The plantation was frequently used by local people for fuel material collection.

(ii) **Horticulture**: The horticultural plot was 14 years-old. It was established by the Regional Agricultural Research Station at Hathazari under the Bangladesh Agriculture Research Council on hill land with a 33 per cent slope. The plantation consisted of fruit trees, most notably *Artocarpus heterophyllus* (jackfruit), *Mangifera indica* (mango), *Psidium guajava* (guava), *Manilkara sapota* (**safeda**), *Litchi chiensis* (litchi) and *Zizyphus mauritiana* (**boroi**). The main undergrowth species in this fruit plantation were *C.viscosum*, *M. pudica*, and *E. odoratum.*

[2]The tree plantations in the degraded hills of Hathazari sub-District were mostly established privately. Face to face interviews with some growers revealed that these hills were leased from the government for 39 to 99 years and the leasing area varied from 1 to a few hundred ha. During the leasing period, the plantation owner was the effective owner of the land in a sense that he/she was entitled to the revenue from the plantation entirely and had the full responsibility to ensure the long-term sustainability of the land.

Figure 1. The soil and litter sample collection site (source: Harvard University, 2010). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

(iii) **Grassland**: The grassland was established in marshy valleys by the Hathazari Dairy Firm. Three fodder grasses, *viz. Pennisetum typhoidum* (napier), *Phaselus mungo* (**maskolai)** and *Panicum maximum* (gini grass) were grown in mixed culture for 9 years.

(iv) **Degraded hill**: The degraded hill was mostly covered with *Imperata cylindrica* (sungrass), some shrubs and a few scattered trees like *Ficus* sp. (**dumur**), and *Calicarpa arborea* (**barmala**). The hill had diverse undergrowth consisting of *C. viscosum*, *M. pudica*, *C. cristael*, *H. sauveolens*, *E. odoratum*, *M. cordata*, and *M. melabatricum*. The mean height and dbh of the trees were 5·6 m and 18 cm, respectively, while the mean height of the undergrowth was 0·96 m. The degraded hill was used as a control land use for the soil characteristics analysis done in this paper.

Soil and Litter Sample Collection

Soil and litter samples were collected in pre-monsoon season in May. Triplicate soil and bulk density samples were collected randomly from 0–10 cm depth from each of the three vegetated land uses and the degraded hill. Pre-weighted cores were used for collecting the bulk density samples. Litter samples, combining both fresh and decomposed litters were collected from three sample plots of size 0·5 m × 0·5 m in each land use.

Laboratory Analysis of Soil and Calculation

Collected soils were studied in the laboratory for colour, structure, stickiness, plasticity, consistency and root characteristics. Soil colour was determined using a Munsell soil colour chart. Bulk density of soils was measured both in moist and oven-dry conditions. Dry bulk density, moisture content, field capacity and maximum water holding capacity were determined from core soil samples. Particle density was determined using oven dry soils. Soil pH was determined in 1:2 soil. Organic carbon concentration of soil (per cent) was determined by wet oxidation method (Chowdhury *et al.*, 1969). The storage of organic carbon in topsoil (megagram per hectare, Mg ha^{-1}) was calculated by using the following formula:

$$S_{oc}^{j} = 10^{8} D_s Bd_{od} C_{org} \qquad (1)$$

where, S_{oc}^{j} = storage of organic carbon (Mg ha^{-1}) in the land use type j ($j = pl, dg$; pl: a vegetated land use, i.e. plantation, dg: degraded hill); D_s = soil depth i.e. 10 cm; Bd_{od} = bulk density of soil in oven dry condition (g cm^{-3}); C_{org} = concentration of organic carbon in soil (Mg g^{-1}); 10^{8} = a factor to convert cm^2 to ha.

The organic carbon concentration (per cent) in litter was calculated by dividing the litter storage by 1·72. The mean annual organic carbon accumulation rates in three vegetated land uses were calculated using the following formula:

$$C_{AR}^{j} = \left(S_{oc}^{pl} - S_{oc}^{dg}\right) T^{-1} \qquad (2)$$

where, C_{AR}^{j} = mean annual organic carbon accumulation rate in a plantation (Mg ha^{-1} y^{-1}); j, S_{oc}^{pl} and S_{oc}^{dg} are as defined in relation to Equation (1); T = age of plantation (y).

An analogous formula of (2) was used to calculate the mean annual organic carbon accumulation rate in litter. Then the accumulation rates in soil and litter were summed-up for each land use type to measure the mean annual organic carbon accumulation rate on ground.

Multiple comparisons of means of all soil parameters measured were carried out with Dunnett-C test of significant difference using SPSS®.

Carbon Sequestration Potential and Revenue

The carbon sequestration potential and the present value of revenue flow in the degraded hills of Chittagong were estimated for hypothetical *A. auriculiformis*[3] plantations of rotation age 15 years. These plantations were assumed to supply carbon credits to voluntary carbon markets. The plantation owners could be individual owners, co-operatives or private firms[4] and are assumed to receive the international carbon market price for the credits [1 credit = 1 Mg of carbon (MgC)] generated through the carbon sequestration in the plantations.

The carbon credits would be issued and hence revenue would be realized at the end of a 5-year period, i.e. at the end of 5th, 10th and 15th years, based on the carbon sequestered both in plant biomass and on ground, i.e. soil and litter. The carbon sequestration on ground was estimated using the mean annual organic carbon accumulation rate found for tree plantations of *A. auriculiformis*. The credits expiring at the end of the first crediting period would be reissued with additional credits earned in the second crediting period and those expiring at the end of the second crediting period would be reissued with those accumulated in the third crediting period. This effectively means the credits earned and revenue generated at the end of second crediting period were actually from a 10-year period and at the end of third crediting period from a 15-year period. Therefore, the carbon sequestered potential in a period can be estimated as follows:

$$C^{i}_{seq} = \left(C^{biomass,i}_{seq} + iC^{aa}_{AR}\right)A \tag{3}$$

where, C^{i}_{seq}= carbon sequestrated (million Mg) in *A. auriculiformis* plantation in a period of length i years (i = 5, 10, 15); $C^{biomass,i}_{seq}$= carbon sequestered in plant biomass in a period (Mg ha^{-1}); C^{aa}_{AR}= mean annual organic carbon accumulation rate in *A. auriculiformis* plantation [(Mg ha^{-1} y^{-1}) (recall Equation (2)]; i = length of period (y); A = area available for plantation (mha).

For plant biomass carbon sequestration in 5, 10 and 15 years we used as proxy the average biomass carbon stock of 6-, 11- and 15-years old *A. auriculiformis* plantations, respectively (estimated by Shin *et al.,* 2007). Since the plantations studied by Shin *et al.* (2007) are located in the same hill range as our study site, these biomass carbon stocks can be considered as good proxies for our estimation.

Finally, the present value of revenue flow from carbon sequestration for 15-year plantation in degraded hills of Chittagong district was estimated using the following formula, which was adapted from Olschewski *et al.* (2005):

$$PV_{Seq} = \sum \frac{p_{carb} C^{i}_{seq}}{(1+r)^{i}} \tag{4}$$

where, PV_{Seq}= present value of potential revenue from carbon sequestration (in million US\$, MUS\$); p_{carb}= carbon price (US\$ MgC^{-1}); r = annual market interest rate; C^{i}_{seq} and i are as defined in relation to Equation (3).

EFFECT ON SOIL CHARACTERISTICS

Physical Properties and Bulk and Particle Densities

The physical properties of soil under the different land uses studied varied mainly in terms of the presence of fine to medium roots. In the grassland more roots were found compared with other land uses (Table I). The moist bulk density of soil in the grassland was significantly ($p < 0{\cdot}05$) higher than other three land uses, while the dry bulk density of soil in the tree plantation was significantly higher than that in other three land uses (Table II). The higher dry bulk density in the tree plantation might be due to the frequent visit to this plantation by people from nearby localities for fuel wood and litter collection, which made the site compact. This finding was in contrast with Jiménez *et al.* (2007), who found lower dry bulk density in soil under mixed plantation established on degraded pasture in the Caribbean lowland of Costa Rica compared with that in degraded pasture land. The dry bulk densities of soil in the tree plantation and the degraded were 1·44 and 1·35 g cm^{-3}, respectively. The particle densities of soil in all land uses studied did not differ significantly from each other (Table II).

Moisture Content, Maximum Water Holding Capacity and Field Capacity

Soil moisture content in the grassland was significantly higher than that under the other three land uses and this probably explains why the dry bulk density was much lower than the moist bulk density in the grassland (see Table II). The maximum water holding capacity under the grassland

[3]*A. aurifuliformis*, for its good growth performance on poor sites (see, for example, Hossain *et al*., 1997), is a preferred species for tree plantations especially in the degraded hills of Chittagong. It is mostly grown in short rotations for construction and furniture timber, pulpwood, tannin and fuelwood.

[4]It is important to note that local communities have significant impacts on the management of and hence the carbon stocks in forest plantations. For example, the variation in stock density and carbon stocks among different *A. aurifulliformis* plantations found by Shin *et al*. (2007) might at least partially be explained by the interventions of local communities. This implies that the accurate measurement and monitoring of carbon stocks in plantations aiming to supply carbon credits to voluntary carbon markets might be expensive and the supply might be associated with a high risk. Recognizing these facts, it should be noted that the management regime, and hence the carbon stocks in the plantations might be different from the one assumed here, should the communities be in charge of them. However, this discussion is outside the scope of this paper.

Table I. Physical properties of soil under four different land uses in Chittagong District, Bangladesh

Land use	Physical properties of soil
Tree plantation	Reddish-brown colour; sub-angular blocky structure; non-plastic and non-sticky (wet); few fine to medium roots were present
Horticulture	Greyish-brown colour; sub-angular blocky structure; slightly plastic and sticky (wet); fine to medium roots were common
Grassland	Dark brown colour; sub-angular blocky structure; non-plastic and non-sticky (wet); fine to medium roots were common
Degraded hill	Reddish-brown colour; sub-angular blocky structure; non-plastic and non-sticky (wet); few roots were present

Table II. Physico-chemical properties of soil under four different land uses in Chittagong District, Bangladesh

Land use	Bulk density ($g\,cm^{-3}$)		Particle density ($g\,cm^{-3}$)	Moisture content (per cent)	Max. water holding capacity (per cent)	Field capacity (per cent)	Soil pH (1:2 water)
	Moist soil	Oven-dry soil					
Tree plantation	1·63 a	1·44 a	2·16 a	12·64 a	30·38 b	19·94 b	5·40 ab
Horticulture	1·54 ab	1·26 d	2·03 a	22·53 ab	44·48 a	26·09 b	4·70 a
Grassland	1·77 c	1·28 cd	2·02 a	46·12 cd	55·48 c	45·78 a	4·50 a
Degraded hill	1·53 b	1·35 b	2·07 a	16·41 b	37·31 b	18·61 b	5·43 b

Different letters in the same column indicate significant difference ($p < 0{\cdot}05$) among mean parameter values of different land uses.

and the horticulture was significantly higher than that under the degraded hill. The moisture content of soil at field capacity was significantly higher in the grassland (45·78 per cent) than that in other three land uses. Among four different land uses, field capacity was the lowest for the degraded hill areas (18·61 per cent). (Table II).

Soil pH

Both the grassland and the horticulture showed significantly lower pH compared with the degraded hill areas. However, no such effect was found for the tree plantation (Table II). Lower pH in the grassland and the horticulture could be due to the marshy condition of the land and the presence of elemental sulphur. The elemental sulphur may initiate sulphur oxidation under aerobic conditions which leads to sulphuric acid formation and consequently very low pH, sometimes even below 3·0 (Brandy, 1990). Lower soil pH under the grassland and the horticulture this was certainly associated with higher organic matter contents (see Table III). This organic matter at various stages of decomposition releases acids, which lower soil pH.

Concentration, Storage and Annual Accumulation Rate of Organic Carbon

The soil organic carbon concentrations at 0–10 cm depth under all three vegetated land uses were significantly higher than that for the degraded hill areas (Table III). This finding is consistent with Jimérez *et al.* (2007) who reported that the soil organic carbon concentration in a 14-year old mixed plantation in the Caribbean lowland of Costa Rica was significantly higher than that in degraded pasture. The concentration under the grassland (1 per cent) was about 5-times higher than that under the degraded hill areas (0·19 per cent). The leaching of organic carbon by the rainwater from the hill slopes to the marshes where the grassland was located, and a high and rapid rate of grass litter decomposition might be the explanation for the higher level of concentration under this land use.

Table III. Carbon sequestration (oven-dry basis) under four different land uses in Chittagong District, Bangladesh

Land use	Soil				Litter			OC accumulation rate on ground ($Mg\,ha^{-1}\,y^{-1}$) (x + y)
	Organic matter (per cent)	Organic carbon (OC) (per cent)	OC storage ($Mg\,ha^{-1}$)	OC accumulation rate ($Mg\,ha^{-1}\,y^{-1}$) (x)	OC ($Mg\,ha^{-1}$)	OC storage ($Ma\,ha^{-1}$)	OC accumulation rate ($Mg\,ha^{-1}\,y^{-1}$) (y)	
Tree plantation	0·82 a	0·47 a	6·77	+0·70	0·425 a	0·248	+0·0350	+0·7350
Horticulture	1·72 c	1·00 c	12·80	+1·14	0·080 c	0·046	+0·0006	+1·1406
Grassland	1·44 b	0·83 b	10·46	+0·56	0·089 b	0·052	+0·0020	+0·5620
Degraded hill	0·33 d	0·19 d	2·57	—	0·065 b	0·038	—	—

Different letters in the same column indicate significant difference ($p < 0{\cdot}05$) among mean parameter values for different land uses.

The concentrations for horticulture (0·83 per cent) and tree plantation (0·47 per cent) were lower than that under grassland. On average, the organic carbon concentration under the vegetated land uses we studied was higher than reported (0·79 per cent) by Hassan (1999) for Barkal Series soils, which are also the soils of the study area. However, Haque and Karmakar (2009) found a higher organic carbon concentration (0·83 per cent, i.e. 1·44 per cent organic matter) in a 7-year old *A. auriculiformis* plantation in Chittagong District.

The lower level of organic carbon accumulation under the tree plantation that we studied might be due to the removal of fresh litter from the plantation by the people from nearby (fuelwood and fodder collection) which reduced the decomposable organic matter to supply carbon to the soil. A comparison of the field capacity for the four land uses studied (Table II) with the corresponding organic carbon concentration values (Table III) indicates a linear relationship between them, i.e. the higher that organic carbon concentration in soil the higher is the field capacity of soil. Litter storage and hence organic carbon storage in litter under tree plantations were significantly higher than those under degraded hill areas. The carbon storage under all land uses were higher than that under degraded hill areas (see Table III). Among the land uses studied, the highest mean annual organic carbon accumulation rate on ground was found for the grassland, while the lowest, unlike the organic carbon concentration rate, was found under horticulture (Table III).

CARBON SEQUESTRATION POTENTIAL AND REVENUE GENERATION

Degraded Hills and Carbon Sequestration Potential in Chittagong

The hilly areas in Chittagong District cover approximately 0·27 mha. Uddin and Saheed (2009) estimated that about 80 per cent of the higher hills, which make up about 70 per cent of the hilly area in Bangladesh are degraded. This suggests that, assuming the lower hills are not degraded, then about 0·15 mha hilly area in Chittagong District is degraded.[5] Our estimate using Equation (3) shows that the 15-year *A. auriculiformis* plantations in these degraded hills could sequester 17·07 million MgC in Chittagong District (Table IV).

It should be noted here that the information on the precise area of steep, moderately steep and less-steep hills in

[5]The high hills in Bangladesh are characterized by 200–1000 m elevation above the mean sea-level (MSL), while the low hills by 15–200 m elevation above MSL (Brammer, 2002). The low hills in Chittagong in particular and in Bangladesh in general are mostly occupied with tea plantations, tree and bamboo forests. This justifies the assumption that these hills are not degraded.

Table IV. Potential carbon sequestration in *A. Auriculiformis* plantations in the degraded hills of Chittagong district

Crediting period (y)	Storage of organic carbon ($Mg\ ha^{-1}$)			Carbon sequestration (million Mg)
	In biomass[a]	In soil (10 cm)	Total	
5	22·29	3·68	25·96	3·93
10	65·31	7·35	72·66	10·99
15	101·86	11·03	112·88	17·07

[a]Shin *et al*., 2007.

0·15 mha degraded hill area of Chittagong District is not available. If it were available, then to estimate the carbon sequestration in the degraded hill area of Chittagong District would be possible, using a combination of land uses suitable for different slopes other than just *A. auriculiformis* plantations for all slopes. In that case, the estimated carbon sequestration might be different from the current one.

Carbon Revenue Flow

Next we estimate the present value of revenue flow of above estimated carbon sequestration by using Equation (4). Our estimate was based on three carbon prices, *viz.* 16, 18 and 20 US\$ MgC^{-1}. These prices correspond to the assumption of Shin *et al.* (2007) that the carbon price in Bangladesh could be between 15–20 US\$ MgC^{-1}, and the current carbon price in the international market of about 18 US\$ MgC^{-1} (Point Carbon, 2010). We first estimated the revenue flow using a base interest rate of 5 per cent per year and then did a sensitivity analysis with three higher annual interest rates, *viz.* 7, 9 and 11 per cent per year.[6]

The results, as illustrated in Table V, show that at a price of 16 US\$ MgC^{-1} and an annual interest rate of 5 per cent, the present value (PV) of the carbon revenue for Chittagong District could be about US\$ 288·49 million. At the same interest rate and the current carbon price in the international market, the corresponding present value could be US\$ 325 million. The present value of revenue goes down as the interest rate goes up. For example, at 11 per cent annual interest rate and current international market carbon price, the PV could be about US\$ 176 million for Chittagong District.[7]

[6]The Bangladesh Bank's interest rate for this year is 5 per cent per year and in current decade the rate has varied between 5 and 7 per cent per year. In the call money market in Bangladesh, the weighted average interest rate on lending has fluctuated between 5·04 and 10·27 per cent per year in this decade (Bangladesh Bank, 2010). These well justify our choice of interest rates for the carbon revenue flow estimation and sensitivity analysis.
[7]Applying the analogous the discussion of Chittagong District presented in this paper, we estimate a 0·97 mha of degraded hill area for the whole of Bangladesh, which could sequester 109·36 million MgC [using Equation (3)] in 15-year rotation *A. auriculiformis* plantations and fetch US\$2·09 billion at the current international market carbon price and 5 per cent annual interest rate [using Equation (4)].

Table V. Present value of potential revenue flow (in million US$) from carbon sequestration at different carbon prices and interest rates for *A. Auriculiformis* plantation in the degraded hills of Chittagong District, Bangladesh

Annual interest rate (per cent)	Crediting period (year)	Carbon price		
		US$ 16 MgC^{-1}	US$ 18 MgC^{-1}	US$ 20 MgC^{-1}
5	5	49·21	55·55	61·51
	10	107·92	121·81	134·90
	15	131·36	148·27	164·20
Total		288·49	325·63	360·61
7	5	44·78	50·55	55·98
	10	89·36	100·87	111·70
	15	98·98	111·72	123·72
Total		233·12	263·13	291·40
9	5	40·82	46·08	51·02
	10	74·25	83·81	92·82
	15	74·97	84·62	93·71
Total		190·05	214·51	237·56
11	5	37·27	42·07	46·59
	10	61·91	69·88	77·39
	15	57·08	64·42	71·34
Total		156·26	176·38	195·32

It can be noted that the PV of revenue flow could actually be higher than currently estimated. This is because there are other suitable tree species for plantations in the degraded hilly areas of Bangladesh, such as *Aphanamixis polystachya* and *Lagerstroemia speciosa* (see Shin *et al*., 2007), which sequester more carbon than *A. auriculiformis*.[8]

It can also be noted that the net present value of the revenue flow of carbon, although not estimated here, is largely expected to be positive because, as explained below, it is realistic to assume that that total cost per MgC of carbon sequestration in Bangladesh[9] is well below even the lowest carbon price we consider, i.e. US$ 16 per MgC.

The total cost of carbon sequestration can be broken down into two categories, *viz.* the production cost and the transaction cost. The production cost may originate from site and soil preparation, nursery raising, tree planting, weed management, pest and disease control and labour. Austin *et al.* (1999) and Hardner *et al.* (2000) estimated that for developing countries like India, China, Brazil and Thailand the production cost per MgC is less then US$ 5.0 if the sink projects are developed in lands having few opportunity costs. The degraded hills in Bangladesh hardly produce anything economically important except sungrass and some fuelwood, and hence the opportunity cost of carbon sequestration plantations in these hills for must be very low[10]. Therefore, considering the fact that Bangladesh has almost the same socio-economic setting as India, a production cost less than US$ 5 per MgC is realistic for the sequestration plantations we analysed.

The transaction cost includes all the costs associated with transferring the carbon credits from the producers to the potential buyers such as cost of carbon accounting and verification. Global estimate for transaction cost varies from US$ 52–US$ 325 per ha (see for example, Smith and Scherr, 2002). Given the fact that the *A. auriculiformis* plantations we analysed here could sequester about 112·88 MgC ha^{-1} (see Table IV), the transaction cost in these plantations could range from US$ 0·46 per MgC to US$ 2·88 per MgC. Therefore, the cost of sequestration in our plantations could be between US$ 5·46 per MgC and US$ 7·88 per MgC or less.

DISCUSSION AND CONCLUSIONS

The soil characteristics under three vegetated land uses, *viz. A. auriculiformis* plantation, horticulture and planted grassland established in the degraded hilly area of Chittagong District, Bangladesh were studied and compared with those under degraded hill areas. The findings suggest

[8]In addition, accounting for the monetary value of environmental services such as watershed protection and erosion control of the carbon sequestration of the plantations could push up the revenue a bit further.

[9]There is no study, to the best of our knowledge, estimating the cost of carbon sequestration under tree plantations in Bangladesh.

[10]These degraded hills are source of soil erosion and sedimentation which cause damage to agricultural and fisheries in flatland areas downstream every year. Therefore, bringing these hills under vegetation cover could actually have some opportunity benefits.

that the change of land use from degraded hill to vegetated land use had changed the soil characteristics. The findings also suggest that the fertility status of the wastelands like degraded hills could be improved by bringing them under vegetated uses, and these types of uses could ensure the environmental sustainability of degraded hills in the Chittagong District in particular and in the whole of Bangladesh in general.

We also estimated carbon sequestration potential and carbon revenue of the degraded hills of Chittagong District using hypothetical *A. auriculiformis* plantations grown in a 15-year rotation. The results showed that the plantations could sequester over 17 million MgC. The present value of revenue flow of this carbon sequestration at the current international carbon market price and prevailing market interest rate could be about US$ 325 million for Chittagong. The revenue could further be increased, should the monetary value of the environmental services such as watershed protection, erosion control and biodiversity conservation to be generated by these plantations be accounted for. Further, these hills could also be afforested or reforested with some other tree species which might assimilate even more carbon than the *A. auriculiformis*, which implies more carbon sequestration and more carbon revenue than calculated. These finding suggests that tree plantations for carbon sequestration could be a sustainable use for degraded hills of Chittagong District in particular and the whole of Bangladesh in general both economically and environmentally. However, these plantations must take into a careful consideration the socio-economic conditions and resource needs of communities living in and around these hills, since the interventions of these communities to influence the management regime of, and hence the carbon stocks in such plantations.

Although we did not estimate the net present value of the carbon, it is expected to be positive since the cost per MgC of sequestration in plantations is assumed to be well below even the lowest carbon price considered, i.e. US$ 16 per MgC. Future research (using primary data for the estimation the net present value of carbon sequestration revenue flow in the degraded hills of Bangladesh under tree plantations) considering the revenues from timber and environmental services under different risks could provide interesting and important insights.

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