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POTENTIAL OF CARBON BENEFITS FROM *Eucalyptus* HYBRID IN DRY-DECIDUOUS COPPICE FOREST OF JHARKHAND

Sanjay Bala[1], Soumyajit Biswas[1] and Asis Mazumdar[1, 2]
[1]Regional Centre National Afforestation and Eco-development Board, Ministry of Environment and Forests, Government of India, Jadavpur University, Kolkata, India
[2]School of Water Resources Engineering, Jadavpur University, Kolkata, India
E-Mail: asismazumdar@yahoo.com

ABSTRACT

Carbon (C) is sequestered by the plant photosynthesis and stored as biomass in different parts of the tree. The present study illustrates physical carbon sequestered in *Eucalyptus* hybrid coppice forest over a period of time in the Chakulia Forest Range of Dhalbhum Forest Division, Jharkhand and potential of getting carbon benefit through Clean Development Mechanism (CDM) or Reducing Emissions from Deforestation and Forest Degradation (REDD). Empirical equation has been derived through curve fitting by using PASW Statistics (SPSS Inc.) to calculate the carbon content of Eucalyptus tree with known diameter and height. For known diameter the equation is $y = 4.57 - 162.05x + 1761.80x^2$ or $y = 14.25 - 372.53x + 3160.37x^2 - 2831.88x^3$ and with known height the equation is $y = 0.00458465x^{3.1785456}$ where 'y' represents Carbon (kg) content of a tree with Diameter/Height 'x' (meter) and applying correlation models it has been found that the Carbon content of a tree has a better relationship with Diameter over Height of the tree. The study also concludes that on an average the C content of a *Eucalyptus* hybrid on dry weight basis was found to be 45.91% as measured by CHN analyzer. The carbon sequestration potential by the Eucalyptus coppice forest was 13.07 tC ha^{-1} (ton Carbon per hectare) in 6 years, with an average annual increment of 2.18 tC ha^{-1}. The present study have shown the corresponding carbon benefits of Rs. 1840/- and Rs. 3200/- under the carbon price of \$5 and \$10 per ton of CO_2 on per hectare per annum for the 6 years old Eucalyptus coppice forest.

Keywords: carbon sequestration, *Eucalyptus* hybrid, coppice forest, correlation model, cleans development mechanism (CDM).

1. INTRODUCTION

There is general consensus that the increasing concentration of greenhouse gases (e.g. CO_2, CH_4, N_2O, O_3) have led to changes in the earth's climate and a warming of the earth's surface. Furthermore, there is agreement that anthropogenic activities, principally the burning of fossil fuels, contribute significantly to this increase of atmospheric CO_2 (Karl and Trenberth, 1999). The Earth's atmospheric CO_2 concentration has risen to nearly 30% since the mid-1800s. Latest predictions of the International Panel of Climate Change (IPCC) suggest that by 2100 the globally averaged surface air temperature will increase by 1.4-5.8°C and the average sea level will rise to between 8 and 88 cm, leading to major disturbances for human settlements and natural ecosystems (IPCC, 1997).

Terrestrial ecosystem carbon (C) sequestration can reduce the rate of buildup of greenhouse gases in the atmosphere and therefore can contribute to a better human adaptation to current and future environmental changes. Forest eco-system plays a significant role in the climate system. Trees are large organisms that store carbon throughout their life and release it through decomposition. Since forests are important carbon sinks and sources, assessing forest carbon budgets has received much attention in recent years (IPCC, 2000, 2001, 2007). There is a perception that humans must alter land use practices to reduce the rates of climate changes and alleviate any resulting negative social, economic, and environmental impacts. Carbon losses or gains in forests may result through afforestation, reforestation or deforestation. A recently published review of the economics of climate change stated that 18% of total annual greenhouse gas emissions today are caused by deforestation. Forest ecosystem C sequestration is of particular interest to researchers and policy makers because, at global scales, forests account for 80-90% of terrestrial plant C and 30-40% of soil C (Landsberg and Gower, 1997). Forests and forest soils have large capacities to both store and release C (Cannell *et al*., 1992), and detailed forest ecosystem C budgets are helpful for improving our understanding of the terrestrial C cycle and for supporting the decision-making process in forest management.

Carbon is held in different natural stocks in the environment. Natural stocks are oceans, fossil fuel deposits, terrestrial system and atmosphere. In the terrestrial system, carbon is sequestered in rocks and sediments, wetlands and forests, and in the soils of forestland, grasslands and agricultural land. A major part of the globe's terrestrial carbon, is sequestered in the standing forests, forest under-storey plants, leaf and forest debris, and in forest soils. A stock that is receiving carbon is called a "sink" and one that is releasing carbon is called a "source." Flows of carbon from one stock to another are viewed as carbon "fluxes", for example, from the atmosphere to the forest. Carbon sequestration is the extraction of the atmospheric carbon dioxide and its storage in terrestrial ecosystems for a very long period of time. Forests offer some potential to be managed as a carbon sink. Plants store carbon for as long as they live, in terms of live biomass. Once they die, the biomass becomes a part of the food chain and enters the soil as soil carbon. If the biomass is incinerated, the carbon is re-emitted into the atmosphere as Carbon dioxide is free to move in the carbon cycle. Unlike many plants and most crops, which have short lives or release much of their carbon at the end of each season, forest biomass accumulates carbon over decades and centuries. Furthermore, carbon accumulation potential in forests is large enough that forests offer the possibility of sequestering significant amounts of additional carbon in relatively short periods.

There are four components of carbon storage in a forest ecosystem. These are trees, plants growing on the forest floor (under-storey material), leaf litter and other decaying matter on the forest floor and forest soils. Carbon is sequestered in the process of plant growth as carbon is captured in plant cell formation and oxygen is released. As the forest biomass experiences growth, the carbon held by the plant also increases forest stock. Simultaneously, plants grow on the forest floor and add to this carbon store. Over time, branches, leaves and other materials fall to the forest floor and may store carbon until they decompose. Again, forest soils may sequester some of the decomposing plant litter through root/soil interactions.

Options to increase carbon storage in forests include protecting forest lands and reducing the conversion of forest lands to non forest purpose. Four major strategies are available to mitigate carbon emissions through forestry activities: i) to increase forested land area through reforestation, ii) to increase the carbon density of existing forests at both stand and landscape scales, iii) to expand the use of forest products that sustainably replace fossil fuel CO_2 emissions, and iv) to reduce emissions from deforestation and degradation. These strategies are covered under Clean Development Mechanism (CDM), which is an arrangement under the Kyoto Protocol allowing industrialized countries with emission reduction commitment to invest through carbon credits in developing countries. Kyoto Protocol adopted on 11^{th} December, 1997 which came into force on 16^{th} February, 2005 gave rise to CDM. Under this system, Annex I countries (Developed countries) will assist Non Annex I (Developing Countries) to implement carbon emission reduction or carbon sequestration projects to meet their own emission reduction targets. Till now, more than 1900 projects have been registered under CDM mostly in energy and waste management sector. However, the CDM has not been as successful in forestry sector Reducing Emissions from Deforestation and Forest Degradation (REDD) (Koul *et al*., 2012). Only afforestation and reforestation are allowed under CDM. Conservation or avoided deforestation has not been considered in CDM. This also has somewhat limited the scope of forestry sector in CDM as natural forests all over the world have been valued monetarily. Australia's first registered project under CCBA (Climate Community Biodiversity Alliance) has quantified carbon stock around 650 t C ha^{-1} $year^{-1}$ (www.climate-standards.com). There is now growing consensus among policy makers, scientists, forestry experts about the importance of conserving and managing existing forests to prevent deforestation and degradation which is a significant contributor of GHG into the atmosphere. Reducing Emissions from Deforestation and Forest Degradation (REDD) (REDD) has become a major issue in International climate change negotiations. REDD in developing countries, substitution of carbon through forestry activities, and some of undefined strategies like restoration. REDD was first introduced by United Nations Framework Convention on Climate Change (UNFCCC) at its 11^{th} session of Conference of Parties (COP) of UNFCCC in Bali, Indonesia the importance of REDD in carbon mitigation was further reinforced. At COP 15 in Copenhagen, the final accepted draft known as Copenhagen Accord, REDD was the only issue that gained some benefits from the negotiations. However till date a consensus on making REDD practicable and marketable mechanism has not been reached. There are differences between developing countries having rich tropical forest cover. There are issues associated with methodologies, monitoring, internal forest policy, indigenous rights etc. once these issues are resolved the REDD mechanism can help in conserving existing forests along with long term sequestration and storage carbon (Koul *et al*., 2012).

The significance of natural forests in carbon sequestration followed by valuation has been done by many forest rich countries. An analysis of carbon stock in South Australian forests, rich in *Eucalyptus regnans* species found that the forests are sequestering and storing carbon at the rate of 12 t C ha^{-1} yr^{-1} (Mckaey *et al*., 2008). The study also emphasized the importance of REDD for even developed and temperate forest rich countries like Australia, Russia, Canada and United States. In another study, it was elucidated through modeling that one fifth of fossil fuel emission is actually sequestered and stored by threatened tropical forests of Africa and Amazonia. The tropical forests which are under threat of deforestation and degradation are actually capturing 4.8 billion tons of carbon dioxide each year (Annon, 2009). According to State Forest Report, 2011 India has 21.05% of geographic area under forest. India forests have been valued US $ 120 billion for 24,000 mt CO_2 locked in its forests by putting price US $ 5 on one ton CO_2 (Annon. 2009).

This paper presents comparison of different equations for calculation carbon sequestrated in the timber of *Eucalyptus* hybrid with known height and diameter. The paper also aims to assess the eligibility and the scope for realization of carbon benefit generation through carbon sequestration by plantation like reforestation and afforestation project which can be distributed to the poor forest dwellers of 12 Join Forest Management (JFM) villages around the study area through different schemes like CDM/REDD+ as an incentive towards the ecological services rendered by them by protecting the plantation. The outcome of this study likely to help in development of carbon sink projects for additional benefits to the JFM communities engaged in growing as well as protecting these tree species.

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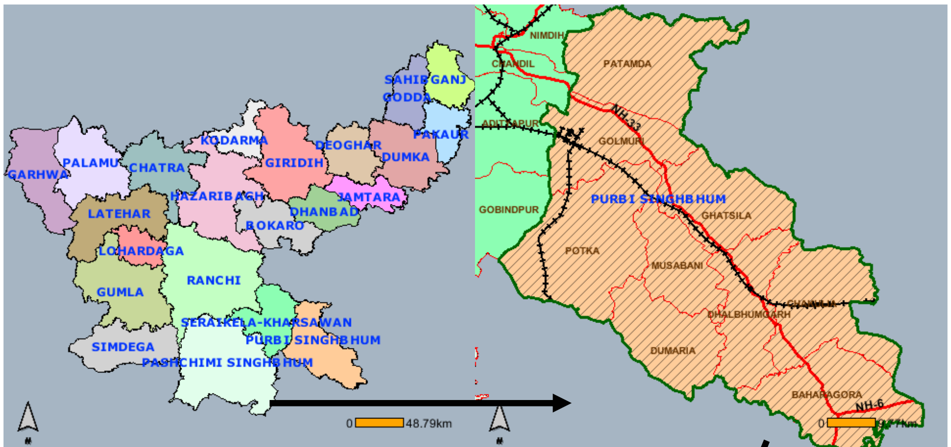
2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in a coppice forest (total area of 1 hectare) of *Eucalyptus* hybrid at Baharagora block (N 22.30285 E 86.72215) of Chakulia forest range under Dhalbhum Forest Division of Jharkhand state (Figure-1). The state of Jharkhand is famous for its rich mineral resources like Coal (32% of India), Copper (25% of India), Uranium, Mica, Bauxite, Granite, Gold, Silver, Graphite, Magnetite, Dolomite, Fireclay, Quartz, Fieldspar, Iron etc. Forests and woodlands occupy more than 29% of the state which is amongst the highest in India. The total geographical area of the state is 79, 714 sq. km. The per capita income is Rs. 4161/- at current prices (Census, 2001).



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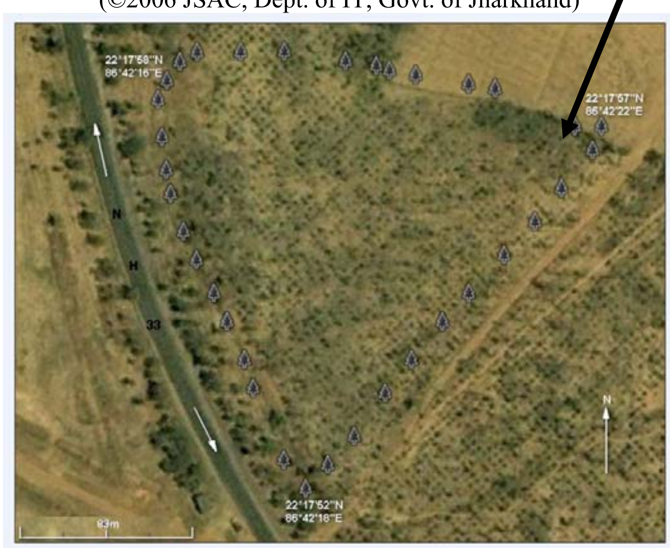

(Source: Primary GPS data plotted on Google Earth)

Figure-1. Map of site location.

Dhalbhum Forest Division created on 2nd January, 1937, is confined to entire East Singhbhum district and a part of Seraikela-Kharsawan district of Jharkhand State. In the north-east of this division lies the state of West Bengal (Puruliya and Midnapur District) and the south of it is bounded by the Orissa (Mayurbhanj District). In the west it is surrounded by the Seraikela-Kharsawan district of Jharkhand. The limits of the longitude are 86°10′ to 86°54′ E and of the latitude 22°20′ to 22°50′ N. The Minimum and Maximum average temperature during last 15 years (1987-2002) ranges from 11.4°C in January to 37.6°C in May. The forests are state-owned and consist of two legal classifications, namely Reserved Forest and Protected Forests. These forests in large compact blocks are confined to the North and south of the Division and a hill range in almost in the middle tending to join the forests of the north and the south. The forest in the plain are scattered and form smaller blocks. The forest of Dhalbhum Forest Division conforms to Dry Peninsular Sal Type (5B/C1c) as classified by Champion and Seth (revised classification 1968) on account of various Biotic and edaphic factors the true character of the forest is differently modified depending on the degree of play of their factors.

After consultation with forest officials altogether 12 JFM villages in the Dhalbhum Forest Division viz. Arjunbera, Bagula, Dhobni, Dumaria, Harindhukre, Hatidih, Kappagora, Karansi, Manda, Roam, Singhpura, and Tetuldanga were selected around the study area whom villagers can get the likely carbon benefit under CDM or REDD +. It has been found that on an average each village is having 122 families. Scheduled Tribe (ST) families are dominating in the villages 56% followed by Others including Other Backward Castes (OBC) 38% and Scheduled Castes (SC) are 6%; the average family sizes are 5.61 for SC, 6.48 for ST and 4.67 for others; the sex ratio (females per thousand males) is 913 i.e., little more than the urban India average but less than rural India average (according to census 2001: India - 933, Rural - 946, and Urban - 900); the villages are having sizable population of cows and goats/sheep - 180 and 217 per village respectively. It is also found that the total forest area in the villages is 2695.15 hectare and available area for cultivation (irrigated, un-irrigated and cultural waste) is 6478.5 hectare.

2.2. Measurement of biomass carbon

To estimate the above ground biomass and amount of carbon stored in the *Eucalyptus* hybrid, 106 trees were felled from the coppice forest of *Eucalyptus* hybrid of Dhalbhum Forest Division. The felled trees were weighed to estimate different tree components. Tree components are defined as: timber (up to 10 cm diameter); small wood (5-10 cm diameter including twigs); total wood (timber + small wood); leaves; above ground weight (total wood + leaves). The length and diameter of each tree components was measured to calculate cylindrical wood volume and the sum of all tree components resulted in total volume of a felled tree. Samples of six felled trees were dried to their constant weight to calculate the wood density (kg/m^3). Above-ground dry biomass weight was calculated by multiplying wood volume with wood density as suggested by Hakkila (1989) and Hart (1991). The fresh weight of wood samples was converted to their air-dry weight by using conversion factor (factor = sample's air dry weight divided by sample's fresh weight) (Dogra and Sharma, 2009). The below ground biomass was calculated using IPCC default value which is above-ground biomass x 0.27 (IPCC, 2006). The carbon content of the samples was analyzed through CHN analyzer (PerkinElmer 2400 series II CHNS/O Elemental Analyzer).

2.3. Data analysis

The data has been analyzed by using the software tool PASW Statistics 18.0 from SPSS Inc. Linear, Logarithmic, Inverse, Quadratic, Cubic; Power, S and Exponential statistical models were compared with the observed data set (Table-1). The best fit model for calculation of carbon in the wood was predicted on the basis of coefficient of determination (R^2). From the best-fit model, correlations among carbon content, diameter and height of a tree was determined.

Table-1. Model description.

Model name		**Dia_carbon and Ht_carbon**
Dependent variable	1	Carbon
Equation	1	Linear
	2	Logarithmic
	3	Inverse
	4	Quadratic
	5	Cubic
	6	Power[a]
	7	S[a]
	8	Exponential[a]
Independent variable		Diameter and height
Constant		Included
Variable whose values label observations in plots		Unspecified
Tolerance for entering terms in equations		0.0001
a. The model requires all non-missing values to be positive.		

The financial analysis represented by parameters on cost effectiveness indicators viz., Net Present Value (NPV) at three different discount rates and Internal Rate of Return (IRR) are also been calculated for the Eucalyptus hybrid plantation. The analysis period selected for the present study was 14 years as the rotation period for Eucalyptus hybrid in coppice forest is varied between 6-8 years. The outcome of the analysis consists of annual incremental carbon sequestration, values on cost effective

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indicators and expected benefits under the selected carbon price scenarios for *Eucalyptus* hybrid plantation.

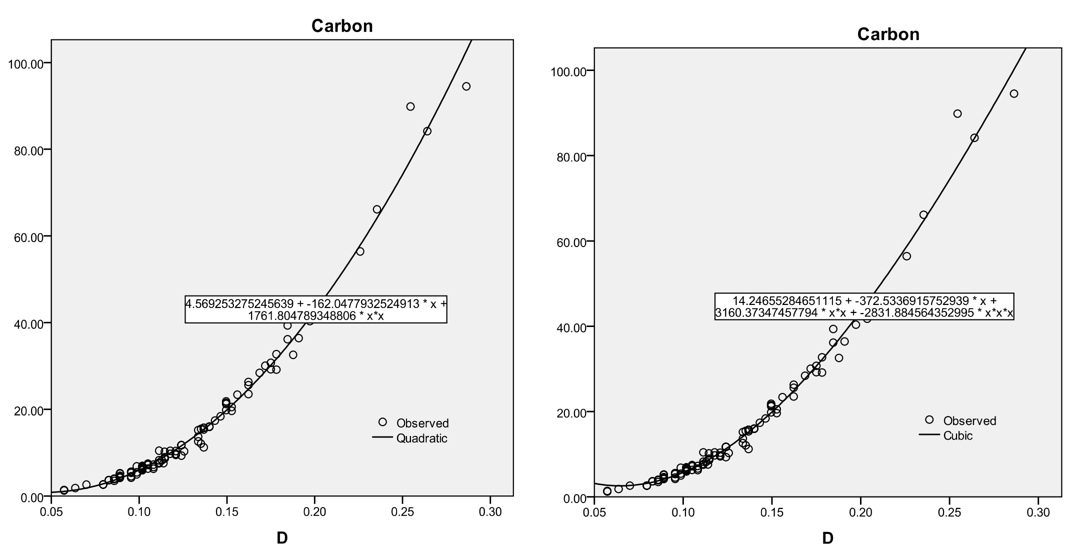
3. RESULTS AND DISCUSSIONS

All the models described in material and methods were analyzed for calculation of carbon content in different tree components. The results revealed that the quadratic and cubic equations are the best for estimating carbon content of a *Eucalyptus* hybrid if we know the diameter of the tree. The results also revealed that Power equation is the best for estimating carbon content of *Eucalyptus* hybrid if we know the height of the tree. Correlations among carbon content, diameter and height of a tree implied that there is a probability to get more accurate value of carbon content of a tree by feeding the tree diameter.

The first experiment takes the Diameter (m) and Carbon (kg) content of a *Eucalyptus* hybrid to test the best curve fitting. A comparison of different prediction equations with known diameter is presented in Table-2 and clearly indicates that the quadratic and cubic equation (Equation 4 and 5) with one dependent variable is best fit with a high value of R^2 (0.989) as compared to other equations. The equations found most suited for calculating carbon sequestration in *Eucalyptus* hybrid compared to other equations by giving high correlation coefficients. The plot of observed values is scattered around a horizontal line with a relatively constant variance meets the assumptions of least square theory (Figure-2). In case of other equations this analysis did not indicate a better stability of variance as compared to quadratic and cubic equations.

Table-2. Model summary and parameter estimates.

Dependent variable: Carbon									
Equation	**Model summary**					**Parameter estimates**			
	R^2	**F**	**df1**	**df2**	**Sig.**	**Constant**	**b1**	**b2**	**b3**
Linear	0.911	1061.480	1	104	.000	-33.296	385.253		
Logarithmic	0.764	336.421	1	104	.000	118.590	48.696		
Inverse	0.574	139.992	1	104	.000	59.254	-5.021		
Quadratic	0.989	4428.050	2	103	.000	4.569	-162.048	1761.805	
Cubic	0.989	3143.068	3	102	.000	14.247	-372.534	3160.373	-2831.885
Power	0.988	8791.968	1	104	.000	3866.018	2.802		
S	0.939	1610.609	1	104	.000	5.157	-.325		
Exponential	0.939	1587.514	1	104	.000	0.838	19.785		
The independent variable is D.									



$$y = 4.569253275245639 - 162.0477932524913x + 1761.804789348806x^2$$

$$y = 14.24655284651115 - 372.5336915752939x + 3160.37347457794\,x^2 - 2831.884564352995\,x^3$$

Figure-2. Carbon content - diameter vs. Carbon.

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ARPN Journal of Engineering and Applied Sciences

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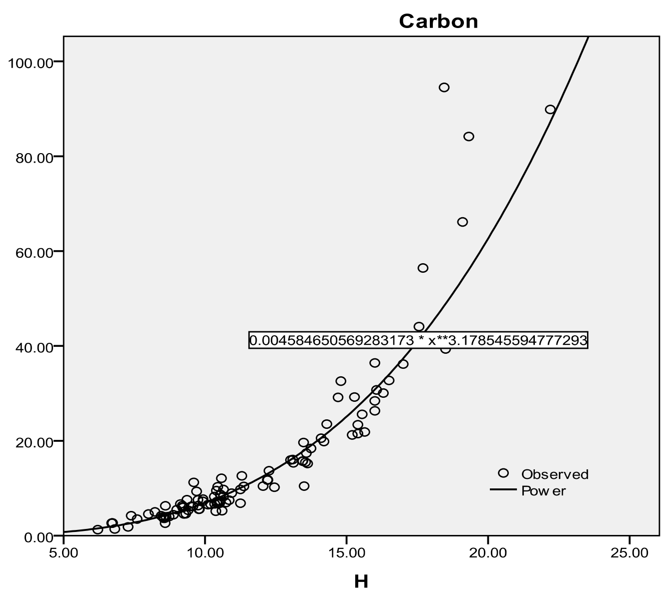
Similarly, the second experiment takes the Height (m) and Carbon (kg) content of a *Eucalyptus* hybrid to test the best curve fitting. A comparison of different prediction equations with known height is presented in Table-3 and clearly indicates that the power equation (Equation 6) with one dependent variable is best fit with a high value of R^2 (0.937) as compared to other equations. The plot of observed values is scattered around a horizontal line with a relatively constant variance meets the assumptions of least square theory (Figure-3). In case of other equations this analysis did not indicate a better stability of variance as compared to power equation.

Table-3. Model summary and parameter estimates.

Dependent Variable: Carbon									
Equation	**Model summary**					**Parameter estimates**			
	R^2	**F**	**df1**	**df2**	**Sig.**	**Constant**	**b1**	**b2**	**b3**
Linear	0.769	346.708	1	104	.000	-39.510	4.686		
Logarithmic	0.665	206.732	1	104	.000	-112.981	52.955		
Inverse	0.546	125.117	1	104	.000	64.686	-537.011		
Quadratic	0.897	448.233	2	103	.000	37.750	-8.125	0.493	
Cubic	0.898	298.381	3	102	.000	21.411	-4.110	0.182	0.008
Power	0.937	1533.991	1	104	.000	0.005	3.179		
S	0.898	916.190	1	104	.000	5.516	-34.840		
Exponential	0.931	1413.336	1	104	.000	0.480	.261		
The independent variable is H.									



$$y = 0.004584650569283173\ x^{3.178545594777293}$$

Figure-3. Carbon content - height vs. carbon.

Applying Kendall's tau_b and Spearman's rho correlation models it is obvious from Table-4 that the Carbon content of a tree has a better relationship with Diameter over Height of the tree. It is easier to measure the Diameter than Height of a tree. The best fits equations also implied that there is a probability to get more accurate value of carbon content of a tree by feeding the tree diameter. The equation is also more simplified for using diameter than height of a tree. Therefore, to calculate the C content in a tree, the best fit equation is **y =** 4.57 - 162.05x + 1761.80x^2 [Where 'y' represents Carbon (kg) content of a tree with Diameter 'x' (meter)], the carbon content of a tree can be calculated easily and more accurately.

Table-4. Correlations among carbon content, diameter and height of a tree.

			Carbon	D	H
Kendall's tau_b	Carbon	Correlation coefficient	1.000	0.940**	0.844**
		Sig. (2-tailed)		0.000	0.000
		N	106	106	106
	D	Correlation coefficient	0.940**	1.000	0.781**
		Sig. (2-tailed)	0.000		0.000
		N	106	106	106
	H	Correlation coefficient	0.844**	0.781**	1.000
		Sig. (2-tailed)	0.000	0.000	
		N	106	106	106
Spearman's rho	Carbon	Correlation coefficient	1.000	0.991**	0.958**
		Sig. (2-tailed)		0.000	0.000
		N	106	106	106
	D	Correlation coefficient	.991**	1.000	.919**
		Sig. (2-tailed)	0.000		0.000
		N	106	106	106
	H	Correlation coefficient	0.958**	0.919**	1.000
		Sig. (2-tailed)	.000	.000	
		N	106	106	106

Total carbon stock of a tree has been evaluated by adding all the carbon contents of stem, branches, leaves and roots of the tree. Samples and accurate measurement of diameter at breast height, height, and weight of foliage were taken from 106 felled trees of *Eucalyptus* hybrid. Volume to mass content conversion of the tree on dry weight basis was calculated based on the basis of samples of six logs covering all the diameter range. The average dry density of the wood was found as 371.075 kg/m^3, whereas raw weight to dry weight conversion factor is 0.445 ± 0.0354. Jacobs and Monteith (1981) found dry wood density for *Eucalyptus tereticornis* ranging from 400 to 600 kg/m^3. The carbon content on dry weight basis was confirmed by using Perkin-Elmer CHN analyzer. On an average the Carbon content of a *Eucalyptus* hybrid on dry weight basis was found to be 45.91%. Carbon content of a tree was established by the works of different Scientists and Researchers, the carbon content in the plant was approximately 50% of the dry matter (WB, 1998). The carbon concentration of different tree parts was rarely measured directly, but generally assumed to be 50% of the dry weight (Losi *et al*., 2003). Work of Losi *et al.* (2003) obtained that measured carbon content of dry sample was 47.8% for *A. excelsum* and 48.5% for *D. panamensis*. West (2003) reported in his paper "Extensive studies in Australia recently of a variety of tree species showed above ground dry biomass generally contain 50% carbon. According to good practices guidelines provided by IPCC the carbon sequestrated value is 45% of the dry biomass (IPCC, 2006).

To calculate the average carbon content of *Eucalyptus* hybrid in a coppice forest the value of Carbon>30 kg in a tree were rejected to minimize the error. In the process the value of some old trees was avoided and the average carbon content of a *Eucalyptus* hybrid was found as 15.64 kg., which includes below ground biomass (according to IPCC, 2006 27% of the above ground biomass is stored as below ground biomass). The carbon sequestrated for different diameters was calculated by using the equation ($y = 4.57 - 162.05x + 1761.80x^2$) for *Eucalyptus* hybrid is shown in Figure-4.

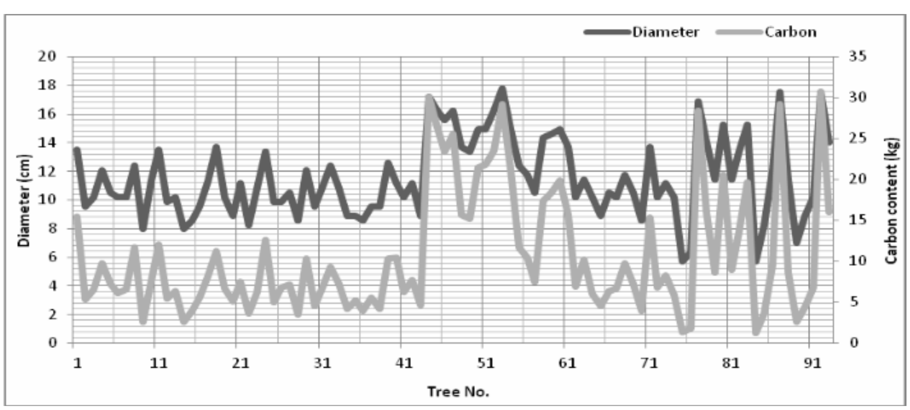


Figure-4. Tree diameter and carbon content.

Based on sample plot data the survival rate in the study area was found 76% with 3m x 3m spacing. Therefore, the carbon sequestrated by *Eucalyptus* hybrid coppice forest was 13.07 t C ha^{-1} in 6 years with an annual increment of 2.18 t C ha^{-1}. In 2009 Dogra and Sharma revealed in their investigations that *Eucalyptus tereticornis* has a potential to sequester carbon is about 50.6 t ha^{-1} in 25 years. Similar studies were conducted and sequestered carbon amount was predicted about 56 t ha^{-1} (Gera *et al*., 2006). The present investigations also revealed that at the age of 25 years the predicted sequestered amount of carbon for *Eucalyptus* hybrid will be 54.5 t ha^{-1}. Studies on carbon sequestration potential of tree species planted on farm lands, viz. planting of Poplar, *Eucalyptus spp.* and Teak have shown the potential range of 1.42 to 2.85 t C ha^{-1} yr^{-1} (Hooda *et al*., 2005). Another study carried out on the farm lands of Punjab has shown a sequestration potential range of 1.42 to 2.54 t C ha^{-1} yr^{-1} for Poplar and *Eucalyptus spp*. (Gera *et al*., 2006). Annual sequestration in terms of CO_2 obtained by multiplying the carbon sequestration values by 3.67 which is 41.56 t ha^{-1} for *Eucalyptus* hybrid coppice forest.

Initial cost of establishment like raising, maintenance and silviculture management for the *Eucalyptus* hybrid coppice forest was Rs. 14760/- per hectare according to State Forest Department, Govt. of Jharkhand The cost effective indicators, viz. Net Present value (NPV) at 10% discount rates and the Internal Rate of Return (IRR) was calculated through online calculator (http://www.calkoo.com/?lang=3&page=21). It NPV was found for *Eucalyptus* hybrid coppice forest Rs. 27,448.99/- per hectare with associated IRR of 58.66% without carbon benefit. The IRR is an indicator of the threshold interest rate below which the loan investment can be obtained to keep the project financially viable. Therefore, the findings from the present observations evident that, the short rotation intervention on the private forest land can be feasible without carbon revenue, if the investment capital is obtained at the rate of 10%.

The eligibility of the plantations depends on the definition of “forest” accepted by the host century for forestry CDM projects according to Indian’s definition of forest. *“A forest is a minimum area of land of 0.05 ha with tree crown cover (or equivalent stocking level) of more than 15% with trees with the potential to reach a minimum height of 2 meters at maturity* in situ” (UNFCCC, 2008b). This definition requires that any land devoid of adequate tree cover, say agriculture, wasteland or forest will have to be either afforested or reforested on a minimum area of 500 m^2 with such trees that have a potential to reach a minimum height of 2 meter at maturity and so densely planted that the crown cover reaches from less than 15% before planting to more than 15% during the maturity of the tree crop (Chauhan and Gera, 2010). In the present study the *Eucalyptus* hybrid on the plantation area of forest land will be able to meet these requirement and will be eligible under CDM as the total plantation area is 1 hectare, the likely crown cover of the Eucalyptus forest will be above 15% as the survival rate of the plantation area 76% and the tree height at maturity is also more than 2 meters as recorded during the field observation.

Likely carbon benefits in the event of a CDM project or similar market mechanism are estimated under two carbon price at $5 and $10 per ton CO_2 assuming the value of 1 US dollar to be Rupees 46/-. The likely carbon benefits for the *Eucalyptus* hybrid coppice forest is Rs. 1840/- and Rs. 3200/- per hectare per year under the carbon price of $5 and $10 a ton of CO_2, respectively. If the plantation area of *Eucalyptus* hybrid is proposed as marketable carbon credit project, the coppice forest of *Eucalyptus* hybrid can fetch higher price if the project goes by the carbon estimation adopted here. On a conservative estimate of US$2 per ton CO_2 the *Eucalyptus* hybrid coppice forest will generate US$ 95 or INR. 4412/- per hectare. This estimate may be increased with the increase of age of the trees as well as may further go down if leakage and project emission is accounted. A major part of this amount by carbon benefit can be distributed to the forest fringe dwellers who are directly dependent on forest and forest produce for their livelihood on account of providing ecosystem services which can certainly motivate them for undertaking plantation as well as protection of tree species in forest land as well as on private lands.

4. CONCLUSIONS

India has emphasized the significance of REDD+ mechanism-that is avoidance of deforestation along with suitable forest management, stock improvement and afforestation. These issues are mainly associated with methodology and indigenous forest dwelling community rights. Unless these barriers are removed REDD + could become imperative in abatement of increased concentration of CO_2. The present study demonstrates the significance of *Eucalyptus* hybrid forest in sequestering carbon. The study illustrated that the carbon sequestrated by *Eucalyptus* hybrid coppice forest was 13.07 t C ha^{-1} in 6 years with an average annual carbon sequestration rate of 2.18 t C $ha^{-1}year^{-1}$. The study also revealed that likely carbon benefits for the *Eucalyptus* hybrid coppice forest is Rs. 1840/- and Rs. 3200/- per hectare per year under the carbon price of $5 and $10 a ton of CO_2 respectively. On a conservative estimate of US$2 per ton CO_2 the *Eucalyptus* hybrid coppice forest will generate US$ 95 or INR. 4412/- per hectare. This estimate will motivate the poor villagers as well as farmers for undertaking plantation as well as protection of *Eucalyptus* hybrid in forest land as well as on private lands. Once the methodological issues associated with REDD + addressed, it will become relatively possible to demonstrate marketable carbon sequestration and other services. The accounting loss and gain of these services which can be monitored for generating additional REDD+ premium is yet to be developed.

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