Biomass and carbon accumulation potential towards climate change mitigation by young plantations of *Dalbergia sissoo Roxb.* and *Eucalyptus* hybrid in Terai Central Himalaya, India

Nabin Raj Joshi[1], Ashish Tewari[1] and Vishal Singh[2]

[1]Department of Forestry and Environmental Science, D.S.B. Campus Kumaun University, Nainital Uttarakhand (India), 263002

[2]Center for Ecology Development and Research, 41, Vasant Vihar Phase -1,Deharadun, India.

*Corresponding authors

E-mail: atewari69@gmail.com

ABSTRACT

Carbon sequestration through forestry plantations has a huge potential in ameliorating global environmental problems such as atmospheric accumulation of carbon dioxide and related climate change. The present study analyzed biomass (dry weight/unit area) and carbon sequestration rates of young plantations of *Dalbergia sissoo Roxb.)* and *Eucalyptus* hybrid in Terai region (a level area of superabundant water) of central Himalaya. Soil carbon was estimated up to 70 cm depth. The plantation of *Dalbergia sissoo* is seed sown and that of *Eucalyptus* hybrid is seedling planted 10 and 8 years old respectively. The density of trees in *Eucalyptus* hybrid plantation was 1825 ind ha^{-1} and that of *Dalbergia sissoo* was 1010 ind ha^{-1}. The total tree biomass for *Dalbergia sissoo* was 29.9 t ha^{-1} in 2009 which increased to 42.85 t ha^{-1} in 2010. In *Eucalyptus* hybrid the total forest vegetation biomass was 43.75 t ha^{-1} in 2009 which increased to 59.45 t ha^{-1} in 2010. The young *Eucalyptus* hybrid forest is sequestrating carbon at 7.89 $tha^{-1}yr^{-1}$ and *Dalbergia sissoo* forest at 6.47 t $ha^{-1}yr^{-1}$ .The soil carbon concentration in both forests were estimated up to 70 cm depth. Soil carbon percent in *Dalbergia sissoo* forest ranged between 0.50 to 2.66, and 0.46 to 1.85 in *Eucalyptus* hybrid forest. Distribution of vertical soil carbon percent in both forest plantations decreased with the soil depth in both the plantations.

KEYWORDS: Biomass, Carbon, Central Himalaya, Diameter at breast height, India, Plantation, Sequestration, and Terai

{**Citation:** Nabin Raj Joshi, Ashish Tewari, Vishal Singh. Biomass and carbon accumulation potential towards climate change mitigation by young plantations of *Dalbergia sissoo Roxb.* and *Eucalyptus* hybrid in Terai Central Himalaya, India. American Journal of Research Communication, 2013, Vol 1 (4): 261-274} www.usa-journals.com, ISSN: 2325-4076.

INTRODUCTION

The Kyoto Protocol to the United Nations Framework Convention on Climate Change(1997) established the principle that carbon sequestration by forests can be used by participating nations to help meet their respective net emission reduction targets for carbon dioxide (CO_2) and other greenhouse gases. The United Nations Framework Convention on Climate Change (UNFCCC) aims to stabilize the greenhouse gases (GHGs) in the atmospheres (UNFCCC, 1993). Several studies have found that growing trees to sequester carbon could provide relatively low-cost net emission reductions for a number of countries (Stavins 1999).

Changing climate is one of major global problems triggered principally by anthropogenic emissions of Green house Gas (GHG). As about 20% of GHG emissions come from forest carbon sources such as deforestation and forest degradation, forest carbon finance is at the centre of future global GHG mitigation strategy. Nevertheless, considering other environmental and social benefits of forests, initiatives have been proposed to consider co-benefits of forests while initiating forest carbon projects. REDD+ is one of such initiatives that have been under consideration globally, that supports the idea that forests should not only be considered as carbon storage, but also for their potential to supply other co-benefits, such as biodiversity conservation, conservation of carbon and other associated social and environmental goods and services

Carbon dioxide is constantly exchanged between the atmosphere, the oceans and terrestrial ecosystems. Vegetation and soils can accumulate carbon, thus reducing the rate of CO_2 build-up in the atmosphere that is responsible for climate change. This opportunity and its potential implications for climate protection started to be recognized in the late 1980s in the discussions leading to the global environmental summit that took place in 1992 in Rio de Janeiro. Concern about rising atmospheric concentrations of greenhouse gases (Wigley 1993) has prompted the search for methods of sequestering carbon in plant biomass. Due to cost effectiveness, high potential rates of carbon uptake, and associated environmental and social benefits, much attention has focused on promoting tropical forestry for offsetting carbon emissions (IPCC 1992).

The area of forest plantation was about 140 million ha in 2005 and increased by 2.8 million ha yr^{-1} between 2000 and 2005, mostly in Asia (FAO, 2006a).The global forest cover is 3952 million ha, which is about 30 percent of the world's land area (FAO, 2006a).Most relevant for the carbon cycle is that between 2000 and 2005, gross deforestation continued at a rate of 12.9 million ha yr^{-1}. This is mainly as a result of converting forests to agricultural land, but also due to expansion of settlements, infrastructure, and unsustainable logging practices (FAO, 2006a; MEA, 2005b). In the 1990s, gross deforestation was slightly higher, at 13.1 million ha yr^{-1}. Due to afforestation, landscape restoration and natural expansion of forests, the most recent estimate of net loss of forest is 7.3 million ha yr^{-1}. The loss is still largest in South America, Africa and South East Asia. This net loss was less than that of 8.9 million ha yr^{-1}in the 1990s.

Reforestation is an important technique for climate change mitigation. During forest growth, atmospheric carbon is taken up by plants and incorporated into their biomass and the soils and it resides on the ecosystem for a period of time. In this manner, reforestation is a means for carbon sequestration. The 'service' provided by forest to sequester carbon has increasingly been appreciated and its value can now be sold through various carbon trading mechanisms. A tool is required to facilitate assessment of the potential of carbon sequestration on various reforestation settings. Such information is very valuable for practitioners and policy makers when formulating reforestation strategy. Carbon sequestration through planted forests serves as sizeable sink for atmospheric CO_2 both in temperate and tropical areas (Houghton et al., 2000; Fang et al., 2001).

Shisham *(Dalbergia sissoo Roxb.)* family Papilionaceae, is a native species of Indian subcontinent while (*Eucalyptus* hybrid) family Myrataceae native species of Australia. This species is extensively found in the sub-Himalayan tracts of India. Shisham *(Dalbergia sissoo Roxb.)* form a primary seral type forest (Champion and Seth 1968). *Eucalyptus* hybrid is a fast growing exotic species these two species can survive under a variety of conditions but ideally prefer temperatures between 5 and 35^0C and occur up to an altitude of 1500m covering an annual rainfall range of 80-300 cm. These species are extensively considered for plantation programs in India and Nepal owing to their economic and ecological values and high survival and fast growing traits.

As the politics of global warming heats up, countries would be required to furnish detailed statements about their entire carbon budgets. Needless to say forest carbon and trees outside forest would be the major component. However, providing accurate measurements of forest carbon is difficult without precise measurements of biomass. Most measurements of biomass are largely results of a common equation applied over a large area, whereas biomass varies depending upon a variety of factors i.e. age of the stand, species and topography. Errors in estimates of biomass stocks are also believed to result from absence of allometric equations for higher diameter classes in general and for the smaller diameter class in particular (below 10) cm which have faster growing rate than the higher diameter class trees.

The present study focuses on the estimation of the biomass and carbon sequestration rates for the trees with diameter between 6 to15 cm at breast height. Biomass of the forest was calculated from the previously developed allometric equations. Herb shrub biomass was calculated by the destructive harvest method. Data was based on the measurements of the tree species in Terai forest collected during 2009 and 2010.

MATERIALS AND METHODS

Study Area

Dalbergia sissoo is a seed sown 10 year old plantation and *Eucalyptus* hybrid 8 year old seedling raised plantation. The spacing between rows is 4m and with in rows was irregular. The study site is situated in the north Indian state of Uttarakhand; the terai forest is managed by the Terai Central Forest Division of Uttarakhand Forest Department. Geographically terai (a level area with superabundant surface water) forest lies between 29º1'30"N to 29º16'40"N latitudes and 79º13'45"E to 79º31'E longitudes. The climate is sub-tropical monsoonal. The land is nearly level and productive. The soil is deep fertile, moist alluvial loam, conspicuous by free from boulders and gravel (Bargali et al. 1992). The general appearance of the tract is gently sloping towards the south-east. The temperature of this area in the summer is maximum 41^{O} C., average 29.4^{O} C. Average rainfall for the whole of the terai tract is 1,250 mm with 80% occurring between June-September. The pH of the site varied from 6.1 to 6.4. Soil organic carbon percent in the top 30cm was 1.57±0.4%. The natural vegetation in this region is mainly alluvial savannah woodland type 3/151, with some pockets of the Terai Sal forest type 3C/C2c (Champion and Seth, 1968).

Methods

Phytosociological Analysis:

The plantation is of Shisham (*Dalbergia sissoo*) with individuals below 15cm diameter at breast height (d.b.h.) and Nilgiri (*Eucalyptus* hybrid) with individuals below 10 cm diameter at breast height (d.b.h.). 20, 100m^2 plots were identified which were randomly well spread over the plantation area. All trees in the plots were measured for d.b.h. using a Electronic digital calliper (Mitutoyo make, 0-15 cm measuring range) and height using Ravi multimeter and Vertex-IV/transponder. Herbaceous vegetation was sampled in 10, 1×1m^2 random quadrats within the plots. The field data was analyzed following Curtis and McIntosh (1950).

Tree Biomass and Carbon

Site specific allometric equations developed previously 2011 were applied to mean d.b.h of each tree species to calculate the biomass accumulation in different tree components. The average biomass attained was then multiplied to the tree density in the diameter classes.

Biomass accumulation and carbon sequestration

The d.b.h. and height measurement of trees in the selected plots was redone in year second (2010) to assess the change in the d.b.h. The data was subjected to regression analysis to estimate the biomass change of the above ground and below ground components (Mac Dicken, 1997). The net change in biomass (ΔB) between biomass of 2009 (B1) and biomass of 2010 (B2) was taken as annual biomass accumulation ($\Delta B = B_2 - B_1$). The herb biomass values taken at the time of peak production where used as herb biomass accumulation annually.

The sum of ΔB values for different components was taken for addition of biomass in trees and herbs. 50% of ΔB (biomass accumulation for each component) was considered as annual carbon sequestration (Singh et al. 2011, Brown and Lugo, 1982; Roy, 2001).

Herb Biomass

Herbaceous biomass was estimated through destructive harvesting placing 1x1m quadrats at the peak productive time (September –October) in year 2009-2010. The above and below ground parts were separated and analyzed in the laboratory after 72 hours of oven drying at 60^{o}C following (Misra,1968). This value was assumed to be equal to net herb production (Bargali, 1992).

Litter fall

Litter fall was estimated for one year period from 2009-2010. The litter input was determined by 10 randomly placed litter traps on the forest floor. Each trap was 1×1 m^2 and 30 cm deep. Litter was collected at monthly interval on sampling dates and taken to the laboratory. Samples were separated in to leaf, wood, and miscellaneous litter and oven dried at 60^oc to constant weight following (Adhikari et al. 1994), (Lodhiyal et**.** al. 2001)

The total vegetation biomass was obtained by summing biomass values of trees and herbs for the plantations.

Soil parameters

The Ph of each soil sample was determined using a digital PH meter, the nitrogen concentration using a micre-Kjeldahl technique (Peach and Tracy, 1956), phosphorus by spectrophotometry and potassium by flame photometry (Jackson, 1967). Walkey's and Blacks titration method (Jackson, 1967) was used to measure soil carbon concentration.

RESULTS AND DISCUSSION

Stand characteristics and soil parameters

In *Dalbergia sissoo* plantation total tree density was 1010 trees ha^{-1}, the total tree basal area was $8.83m^2$ h^{-1} while it was the tree density in *Eucalyptus* hybrid was 1825 trees ha^{-1} and total tree basal area was 8.57 m^2ha^{-1}. The soil was slightly acidic and the soil organic carbon (SOC) percent in the top soil layer was higher as compared to the lower soil strata(1-30cm) which was 2.66-1.31 in *Dalbergia sissoo* plantation and 1.85- 1.01 in *Eucalyptus* hybrid plantation. The soil nitrogen concentration in this study are similar to the concentration reported for the previous studies for the Terai region (Table7). (Bargali et al. 1991 and Lodhiiyal et al. 1992).

Tree biomass and carbon accumulation

The total biomass of the tree layer in *Dalbergia sissoo* plantation was 29.51 t ha^{-1} which incremented to 42.85 t ha^{-1} in the second year of which 46.12% is contributed by bole, 23.14% by branch, 4.39% by twig, 8.91% by foliage, 9.32% by stump root,6.04% by lateral roots and 2.06% by fine roots, and of that 82.34% biomass was stocked in above ground parts and rest 17.66% was stocked in below ground parts respectively (Table2.).While in *Eucalyptus* hybrid plantation total tree biomass was 43.75 t ha^{-1} which incremented to 59.54 t ha^{-1}in the year two of which about 59.18% is contributed by bole, 8.60% by branch, 1.33% by twig, 8.78% by foliage, 12.48% by stump root, 7.18% by lateral roots and 2.40% by fine roots, here about 82.30% biomass was stocked in above ground parts and rest 17.7% was stocked in below ground parts respectively. (Table4.)

Table1. Tree vegetation analysis and total biomass in the plantation

S.no	Species	Density(indha^{-1})	TBA(m^{2}ha^{-1})	Total biomass in the plantation(t ha^{-1})
1	*Eucalyptus* hybrid	1825	8.18	59.54
2	*Dalbergia sissoo*	1010	8.83	46.85

Table2. Tree biomass and carbon (given in parenthesis) distribution in different components of *Dalbergia sissoo* plantation

Component	Biomass B1(t ha^{-1})	Biomass B2(t ha^{-1})	Net change in biomass ($\Delta B = B_2 - B_1$)	Carbon sequestration rate (ha^{-1}yr^{-1})
Bole	14.01(7.05)	19.65(9.82)	5.64(2.82)	2.82
Branch	6.76(3.38)	10.01(5.005)	3.25(1.62)	1.62
Twig	1.27(0.63)	1.88(0.94)	0.61(0.30)	0.30
Foliage	2.57(1.28)	3.79(1.89)	1.22(0.61)	0.61
Stump root	2.89(1.44)	4.009(2.004)	1.11(0.55)	0.55
Lateral root	1.78(0.89)	2.63(1.31)	0.84(0.42)	0.42
Fine root	0.62(0.31)	0.9(0.45)	0.28(0.14)	0.14
Total	**29.9**(14.95)	**42.85**(21.42)	**12.95**(6.46)	**6.46**

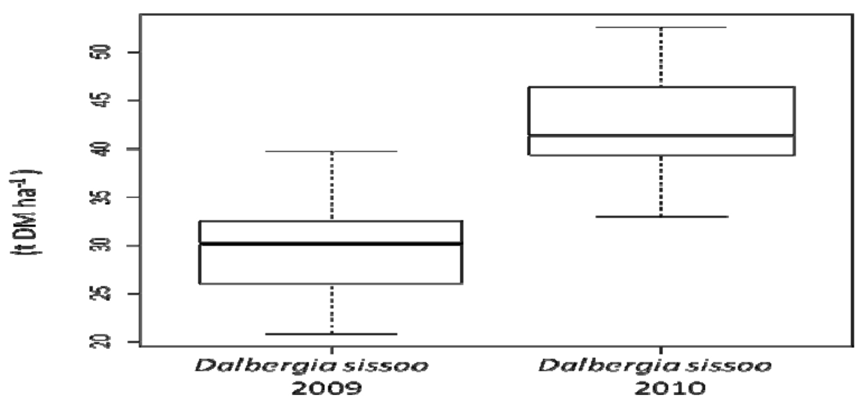

Figure 1: Box-and-whisker plot of above ground tree biomass for 10-year old *Dalbergia sissoo* plantation showing five-number summaries and outliers.

Table3. Summary statistics of sampling of trees in 10-year old *Dalbergia sissoo* plantation

Species/year	Variable unit	Number of plots	Mean	Std. deviation	Half width of confidence interval	Max	Min	Median	Sampling precision
Dalbergia sissoo/2009	Biomass [t ha-1]	20	29.86	4.73	2.21	39.71	20.84	30.20	3.54
Dalbergia sissoo/ 2010	Biomass [t ha-1]	20	42.52	4.93	2.31	52.58	32.88	41.38	2.59

Table4. Tree biomass and carbon (given in parenthesis) distribution in different components of *Eucalyptus* hybrid plantation

Component	**Biomass B1(t ha^{-1})**	**Biomass B2(t ha^{-1})**	**Net Change in Biomass** ($\Delta B = B_2 - B_1$)	**Carbon sequestration rate (ha^{-1}yr^{-1})**
Bole	25.79(12.89)	35.02(17.51)	9.22(4.61)	4.61
Branch	6.45(3.22)	8.55(4.27)	2.1(1.05)	1.05
Twig	0.94(.47)	1.25(0.62)	0.29(0.14)	0.14
Foliage	3.46(1.73)	4.84(2.42)	1.36(0.68)	0.68
Stump root	5.81(2.90)	8.13(4.06)	2.32(1.16)	1.16
Lateral root	0.95(.47)	1.43(0.71)	0.47(0.23)	0.23
Fine root	0.26(0.13)	0.32(0.16)	0.03(0.015)	0.015
Total	**43.66**(21.83)	**59.54**(29.77)	**15.79**(7.88)	**7.88**

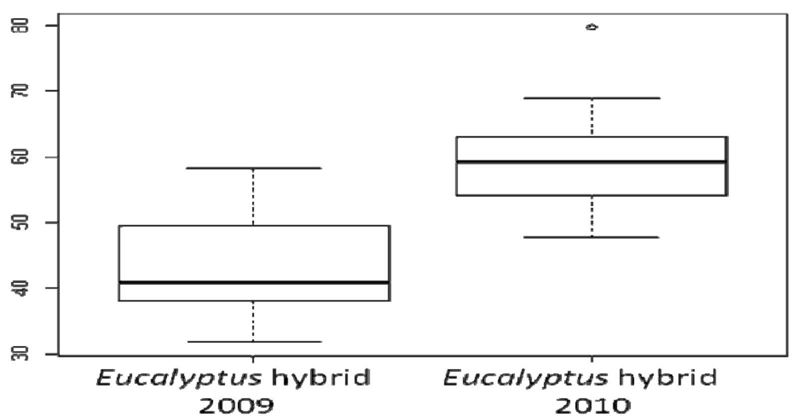

Figure 2: Box-and-whisker plot of above ground tree biomass for 8-year old *Eucalyptus* hybrid plantation showing five-number summaries and outliers.

Herb and litter biomass

The total herbaceous biomass was 3.14 and 1.32 t ha^{-1} in *Dalbergia* and *Eucalyptus* plantation respectively (Table.5). The total forest floor litter biomass in *Dalbergia sissoo* plantation was 1.004t ha^{-1} and this value was 0.68 tha^{-1} for *Eucalyptus* hybrid plantation (Table 6). The forest floor litter of plantations in Terai region in earlier studies is comparable with the values of current studies (Bargali et al. 1992).

Table5. Summary statistics of sampling of trees in 8-year old *Eucalyptus* hybrid plantation

Species/ year	Variable unit	Number of Plots	Mean	Std. deviation	Half width of confidence interval	Max	Min	Median	Sampling precision
Eucalyptus Hybrid/ 2009	Biomass [t ha-1]	20	43.71	8.08	3.78	58.30	31.72	40.87	4.13
Eucalyptus Hybrid/ 2010	Biomass [t ha-1]	20	59.50	7.29	3.41	79.82	47.81	59.23	2.74

Table6. Herb and litter Biomass in the plantation

S.no.	Species	Herb biomass(t ha^{-1})	Litter biomass(t ha^{-1})
1	*Eucalyptus* hybrid	1.32	0.68
2	*Dalbergia sissoo*	3.41	1.004

Total vegetation biomass and carbon sequestration rate

In the present study the rate of carbon sequestration by *Eucalyptus* hybrid was 7.89 t c $ha^{-1}yr^{-1}$ and *Dalbergia sissoo* was 6.47 t c $ha^{-1}yr^{-1}$ which is relatively lesser then that of *Eucalyptus* hybrid of the Terai region. The total vegetation biomass of 3 and 4 year old *Ecualyptus* plantation with 2000trees/ha has been reported to range between 7.68and 49.95t/ha and the annual biomass accumulation values between 8.61$tha^{-1}yr^{-1}$ and 18.74 $tha^{-1}yr^{-1}$ (Bargali et al. 1992) Similarly in a five year old *Dalbergia sissoo* plantation with 625 trees ha^{-1} with the total vegetation biomass was 58.7tha^{-1} and annual biomass accumulation 12.6$tha^{-1}yr^{-1}$ (Lodhiyal et al. 2002) compared to 42.45 t ha^{-1} biomass and 6.46 $tha^{-1}yr^{-1}$ biomass accumulation in the present study. The biomass accumulation rates of the current study are comparable with the study of Lodhiyal et al. (1992) (Table5.). The carbon sequestration rates of this forest are within the range reported for the forest of the central Himalayan region which varies between 2.4 and 5.6 $tha^{-1}yr^{-1}$ (Rana et al. 1989). In the present study it is quite evident that because of close spacing in *Dalbergia* plantation between the plants in rows has an adverse effect in biomass accumulation and presence of ruthless grazing by domestic cattle's and wild elephants further add to the problem. For the proper development and carbon enhancement of these plantation several silvicultural treatments like thinning and pruning and leakage control and monitoring are equally important.

Table7. Soil Carbon, Nitrogen, soil pH, N, P, K and organic matter content of the study sites in two different plantation sites.

S. no	**Soil depth (cm)**	**Soil Carbon (%)**	**PH**	**N (%)**	**P (%)**	**K (%)**
Dalbergia sissoo Plantation						
1	0-10	2.66	6.83	0.15	0.01	0.06
2	10-20	1.54	6.91	0.15	0.02	0.06
3	20-30	1.31	6.95	0.15	0.03	0.06
4	30-40	1.02	6.30	0.21	0.03	0.05
5	40-50	0.85	6.7	0.22	0.04	0.06
6	50-60	0.64	5.7	0.27	0.05	0.03
7	60-70	0.50	5.9	0.23	0.07	0.04
***Eucalyptus* hybrid Plantation**						
1	0-10	1.85	5.82	0.16	0.036	0.06
2	10-20	1.33	5.54	0.15	0.042	0.071
3	20-30	1.01	6.5	0.15	0.033	0.063
4	30-40	0.84	5.5	0.16	0.025	0.048
5	40-50	0.65	5.7	0.18	0.032	0.083
6	50-60	0.83	6.9	0.20	0.026	0.045
7	60-70	0.46	6.3	0.21	0.072	0.024

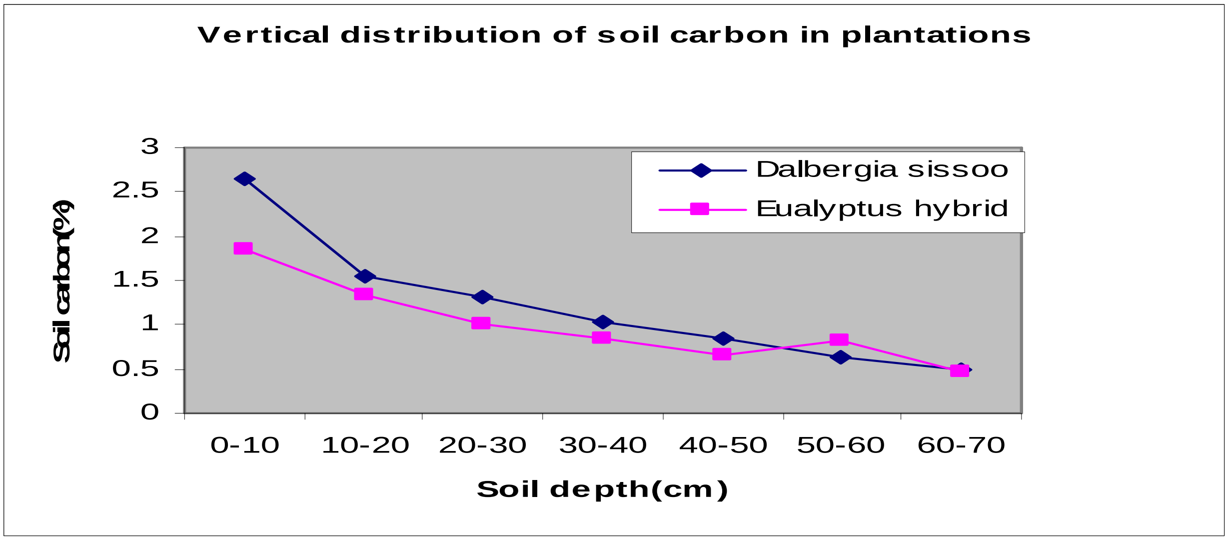

Fig 3: Vertical distribution of soil carbon in *Dalbergia sissoo* and *Eucalyptus* hybrid plantation.

DISCUSSION

The pressures brought by climate change have elevated biomass assessment instrumental to measure the forest's potential as carbon storage and source. Much attention is given to precisely measure how much biomass there is in the forest. A young forest would sequester more carbon than an old forest. Similarly, forests associated with better quality of soils would yield higher carbon sequestration rates. Evidently, different species will behave in a different manner; a faster growing species (*Eucalyptus*, *Sissoo*, *Popular*, etc) would sequester more carbon than a slow growing species (Oaks etc). Also habitat variability caused differences of biomass accumulation, species composition and the allometric relationships of forests. Tropical rain forest has the highest potential of carbon sequestration and following by the dry evergreen forest and the mixed deciduous forest respectively. The carbon allocations in different components of seven dominant forest types of Himalayan region have been studied by Rana et. al. (1989), and they have concluded that the carbon allocation in seven dominant forest types of the region ranges from 166.8 t C ha^{-1} to 440.1 t C ha^{-1}. However information on carbon allocation in very young plantation in the region is not available. Our study reveals that a considerable amount of carbon allocated in these young plantation, which acts as an additional carbon sink in the region.

This evidence indicates the potential for growth to reach the climax stage of succession in the near future. These smaller trees have not the highest carbon sequestration potential but they are relevant in terms of their future potential to grow up. With high carbon sequestration potential in these plantations of Terai region of Uttarakhand, State Forest Department must urgently consider to strictly protect and conserve these forests for sequestering atmospheric CO_2 which can increase carbon sink into the plantation forest. India can contribute to reduce the problem of greenhouse effects regarding global warming and climate changes. Among the global common concerns, climate change has identified as the most important environmental challenges facing humanity. Emissions of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and perflurocarbons are identified as a green house gases caucusing warming of earth globally. Of these CO_2 alone accounts for 60 percent share. Absorbing atmospheric CO_2 and moving into physiological system and plant biomass, and finally into the soil, is considered as the most practical way of removing excess carbon from atmosphere and storing it into biological system. Carbon is thus sequestrated into the plants and then the animals. Studies have established that carbon sequestration by trees and forests could provide relatively low cost net emission reductions. Carbon management in forest is, therefore, one of the most important agenda in India in the 21st century in context of green house gases effects and mitigation of global climate changes. Site specific carbon estimates depends on stand composition, age, site quality and management. Tree plantations have been received considerable attention as a forest restoration strategy. Plantations can facilitate secondary forest regrowth by providing an understory environment more favorable for native plant recruitment than unmanaged degraded habitats (Ren et al. 2008). Planted forests of short- rotation tree species contribution have huge carbon sequestration potential in Indian forests at national and site specific level and which elaborates some possible opportunities for sustainable carbon forestry and the sustainable forest ecosystem management for the alternative solution for carbon dioxide reduction in terms of carbon sink role.

ACKNOWLEDGEMENTS

Authors are thankful to Department of Forestry for providing necessary facilities and encouragement. Authors are also thankful to members of the State forest department for their support in the field data collection, focus group discussions and co-operation throughout the study period.

REFERENCES

Bargali, S.S., Singh, S.P., Singh, R.P., 1992 Structure and function of an age series of Eucalyptus plantations in Central Himalaya. I. Dry Matter Dynamics, *Annals of Botany* 69, 405-411.

Bargali, S.S. and Singh, S.P. 1991. Aspects of productivity and nutrient cycling in an 8-year old Eucalyptus plantation in a moist plain area adjacent to central Himalaya, India . Can. J.For. Res. 21: 1365-1372.

Brown, S., Lugo A.E., 1982. The storage and production of organic matter in tropical forests and their role in global carbon cycle. Biotrop. 14, 161-187.

Champion, H.G. and Seth S.K. 1968. Forest Types of India. Government of India Press, Nasik, pp. 404.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical Forests.

Curtis, J.T. and McIntosh, R.P. (1950). In interrelation of certain analytic and synthetic phytosociological character. Ecol 31: 438-455.

Dudley, N.S., Fownes, J.H.,(1992). Preliminary biomass equations for eight species of fast-growing Tropical trees. 3 *Trop For Sci* 5(1):68-73.

FAO, (2006a): Global Forest Resources Assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147, 320 pp.

Fang, J., Chen, A., Peng, C., Zhao, S., Ci, L., 2001. Changes in forest biomass carbon storage in China between 1949 and 1998. Science 292, 2320–2322.

Houghton, R.A., Skole, D.L., Nobre, C.A., Hackler, J.L., Lawrence, K.T., Chomentowski, W.H., 2000.Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature 403, 301–304.

UNEP, (1993) Information Unit on Climate Change (IUCC), Noordwijk ministerial declaration on climate change (www.cs.ntu.edu.au/homepages/jmitroy/sid101/uncc/fs218.html)

Jackson, M.L. (1967). *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Lodhiyal, N., Lodhiyal, L. S., and Pangtey, Y. P. S., 2002. Structure and function of Shisham forests in Central Himalaya, India: dry matter dynamics. *Annals of Botany* 89, 41-54.

MacDicken, K.G. (1997). A Guide to mountain carbon storage in forestry and agroforestry Projects. Arlington VA (US): Winrock International Institute for Agricultural Development, Forest Carbon Monitoring Programme.

MEA, (2005b): Millennium Ecosystem Assessment. Ecosystems and human well-being: Scenarios. Findings of the Scenarios Working Group. Island Press, Washington D.C.

Mishra, R. 1968. Ecology work book. Calcutta: Oxford and IBH Publishing.

Peach, K. and Tracy, V.N. (1956). Modern methods of plant analysis Vol. 1. Berlin: Springer-Verlag.

Rana, B.S., Singh, R.P. and Singh, S.P. (1989). Carbon and energy dynamics of seven central Himalayan forests. Tropical Ecology 30(2): 253-264.

Ren, H. Jian, S.G., Lu, H.F. (2008). Restoration of mangrove plantations and colonisation by native species in Leizhou bay, South China. *Ecol Res* 23:401–407

Schoene, D. 1983. The valuation and use of site information for Douglas-fir reforestation in Western Oregon Ph.D. Thesis. *Oregon state university, Carvallis Oregon, USA.*

Stavins, Robert N. "The Costs of Carbon Sequestration: A Revealed-Preference Approach." *American Economic Review* 89(1999):994-1009.

Terakunpisut, J. Gajaseni, N. and Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum National Forest, Thailand. *Applied Ecology and Environmental Research* 5(2):93-102.