Carbon Sequestration Potential of Agroforestry Trees (Agroforests) in India

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Abstract: Agroforestry trees (Agroforests) play an important role in global carbon cycle and regulating the biospheric climate. Agroforestry trees are key component of agroforestry systems which store substantial amount of terrestrial carbon (C) and a very significant proportion is fixed in the form of above ground biomass. This paper addresses the potential of agroforestry trees (agroforests) with especial reference to carbon sequestration and carbon finance in India. The indirect method of carbon estimation in the agroforestry trees using volume and regression equation are practically useful compared to direct or harvesting methods. The agricultural lands with substantial agroforests/ trees components are considered to be a major potential sink being capable for storing high amount of C in different agro-ecological systems. Currently, climate change awareness has increasingly gained the momentum being major threat for the survival of biotic community and to address this carbon sequestration in the trees outside forests (TOF) in the form of agro and farm forestry is an economically feasible and practically viable option. Thus, the importance of agroforestry as a sustainable land-use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to biodiversity, soil and water conservation and ultimately to the climate change adaptation and mitigation.
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1. Introduction

Carbon sequestration with best economic, reliable and mass scale option is the need of today to doge the Green House Gas (GHG) emission. Different biological systems from aquatic to terrestrial are found to be potential but practical and synergetic option with mass adoption lies in forestry and agricultural system i.e. agroforestry. There is a growing concern among the scientific community, academicians, planners, policy makers and administrators all over the world for the sustainable development of natural resources. Indiscriminate, unscientific and continuous exploitation of natural resources over the decades are causing severe environmental degradation and affecting the functioning of different ecosystems. In this context, today agroforestry has generated much enthusiasm even among the common people throughout the world. In India considering the Natural Resource Support system, the National Action Plan for Climate Change (NAPCC) under its green India mission has exclusively emphasized the agroforestry interventions. Moreover, recognizing the importance of agroforestry in India, the National Bamboo Mission has been rechristened as National Agroforestry and Bamboo Mission. At policy level, the importance of plantation outside the forest land and the role of Agroforestry, the Hon'ble president of India Mr. Pranab Mukherjee unveiled the first National Agroforestry Policy 2014 on 10th February, 2014 for India in the inaugural session of 3rd World Congress on Agroforestry held at New Delhi becoming first nation in the world to adopt an agroforestry policy. The potential of agroforestry to mitigate climate change and help farmers to adapt the impacts of climate change are a strong driving force behind India's new agroforestry policy.

Climate change has increasingly gained the momentum as a major threat against the survival of biotic community. To balance the atmospheric carbon (C) and their storage in the terrestrial biosphere is a vital way to compensate the emission of green house gases. Agroforestry systems are believed to have higher potential to sequester carbon than pastures or field crops (Sanchez, 2000; Kirby and Potvin, 2007). Global warming is mainly the result of CO_2 levels rising in the Earth's atmosphere and now we have a few years, not decades, to stabilize CO_2 and other greenhouse gases as the present global atmospheric CO_2 level has already touched 406.81 ppm in June, 2016 (https://www.co2.earth/, retrieved on 8th July, 2016). Therefore, to sequester the increasing amount of CO_2, agroforestry can play a pivotal role. Agroforestry known to have the potential to sequester a very significant proportion of carbon in the form of above and below ground biomass, thus agroforestry systems play an important role in regulating carbon cycle to meet out the challenges of climate change.

Although the estimates of C sequestration potential in agroforestry systems are highly variable, ranging from 0.29 to 15.21 t C/ha/y (Nair et al., 2009), depending on the site characteristics, land-use types, species involved, stand age, and management practices. General principle is that 50 % of dry biomass of plants is assumed carbon content (Brown and Lugo, 1982). It is also observed that if agroforestry practices include fertilizer to maximize crop production then that can easily increase carbon sequestration of species such as eucalypts (Koskela et al., 2000). In an agroforestry study by Sharma (1995, 2003) and Sharma et al 2001 in Sikkim found that cardamom based agroforestry system with different tree species like Albizia-Cardamom, Alnus-Cardamom, forest-cardamom and integrated crops restore the carbon. In this manner agroforestry provides many environmental services like biodiversity conservation, enrichment of the soil, temperature regulation, carbon storage, soil moisture conservation, maintenance of water quality-quantity etc and consequently restore the environment. Shamsudheen et al., (2014) reviewed that silvipastoral system sequestered 36.3% to 60.0% more total soil organic carbon stock compared to the tree system and 27.1–70.8% more in comparison to the pasture system

It was observed that deforestation and forest degradation account for nearly 20% of greenhouse gas emission (Shukhdev et al., 2015), however, forests play significant role in forming active carbon pool accounting nearly 60% of terrestrial carbon storage (Wilson and Daff, 2003). Long rotation systems such as agroforestry, home gardens and boundary plantings can sequester significant amount of C in the wood, moreover, carbon sequestration in agroforestry soil also play an important role in carbon storage. Newaj and Shabir (2009) also reviewed the carbon sequestration potential in different land uses with special reference to agroforestry. Indu et al. (2013) reviewed the role of agroforestry systems in carbon mitigation and stated that agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation.

2. Estimation of Carbon in Agroforestry Trees (Agroforests)

Estimates of carbon stock are generally calculated by first measuring the total biomass of the tree population using one of the two approaches. In the first method, the diameter and height of the trees in any agroforestry system are measured for the estimation of volume. The species specific volume equations used to compute the volume of the standing trees. In order to estimate the tree biomass, the volume of individual tree is multiplied by its mean wood density and thus stem biomass is derived. Later, the stem biomass is allowed to multiply by the biomass expansion factor of respective species to derive above ground biomass. The carbon storage for each tree is computed by multiplying biomass values with carbon concentration generally taken as 0.50 (Haripriya, 2000; Smith and Heath, 2002; Heath, 2007 and Smith *et al.* 2007). The above ground biomass and carbon contents of individual trees are summed to obtain total above ground biomass and carbon present in any tree.

The second approach is to apply a regression equation that directly converts external measurements, such as stem diameter and sometimes height to total tree biomass. Individual tree biomass values produced using either of the approach are sum up to derive the biomass of the entire population (plantation), which is then multiplied by a standard value of carbon concentration to produce an estimate of carbon stock (Losi Christopher et al, 2003; Kauppi et al, 1992; Birdsey and Health, 1995; Goodale et al, 2002). Soil carbon is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (Reves, 1997). Soil stores 2 or 3 times more carbon than that which exists in the atmosphere (Davidson et al, 2000). Brown and Lugo (1982) reported 46 to 183 Mg C ha^{-1} for variety of tropical dry forests of the world. Brown *et al.* (1994) also reported 95 to 157 Mg C ha^{-1} for different tropical forests of Malaysia. Shepherd and Montagnini (2001) estimated carbon storage from 1.7 to 26.4 Mg C ha^{-1} in 1-6 yrs old pure plantations of four species *viz. Albizia guachapepele, Dipteryx panamensis, Terminalia amzonia* and *Virola koschnyi*. However, when all these species raised as mixture enhanced the carbon storage from 6.2 to 27.5 Mg C ha^{-1}. However, biomass and carbon estimation using remote sensing and GIS has increasingly gain momentum in the recent past.

As the materials and methods of carbon estimation clearly suggests that in agroforestry systems trees are only taken into account whereas agroforestry system must include the other components like agricultural crops, shrubs, horticultural crops, livestock, fisheries etc. Further, most of the literature and findings of research are based on biomass equation developed for the trees in natural forests which may not hold good for agroforestry trees (agroforests). Though most of studies talks about carbon sequestration potential of agroforestry system but they are silent on crop components with the argument that their role is negligible. In recent times the methodologies have been developed to ascertain the carbon sequestration potential of crops, small shrubs, aquatic lives and livestock. Thus, in the concept of Integrated farming system (IFS) due weightage should also be given to all the components. Therefore in present review, we finds most of the studies on potential of agroforestry trees or agroforests rather agroforestry systems.

3. Tree Carbon Estimation in Indian Scenario

The estimation of tree volume is important task of a forester in forests to get a primary data on growing stock. It helps in decision making process for treating the trees at different stages of its development (Fazakas and Nilsson, 1996). Biomass constitutes a primary data needed for understanding a number of ecological processes like energy flow, water and nutrient cycling in forest ecosystems (Chaturvedi and Singh, 1987; Tiwari, 1994). The biomass estimations in trees are conventionally made by the use of species specific allometric equations and component wise *viz*., stem, branch, foliage and root biomass are estimated in both tree and shrub layer (Mishra, 1968; Odum, 1983; Rai, 1984). The sum of trees and shrub layer formed the total standing biomass therefore, the availability of species specific local regression equations are essential for precisely estimating the forest biomass and carbon storage. However, for many of the tree species at different locations allometric equations are unavailable, therefore developments of equations need to be done for a large number of trees in different areas.

Tiwari and Singh (1984) mapped the forest biomass and carbon in Kumaun Himalya, India using aerial photographs. Tree biomass and carbon was estimated by using biomass equations, mean girth and mean density on reference sites further regression equations were developed between crown cover and basal cover, and between crown cover and stand biomass. Mean basal cover and mean stand biomass for each photo interpreted crown cover class were estimated through these equations. Forest biomass values were substituted for crown cover classes on the interpreted map.

Haripriya (2000) estimated the above ground biomass density and carbon storage in biomass of major forest strata of India using forest volume inventory data published by Forest Survey of India (FSI), Dhradun, based on interpretation of satellite data, aerial photographs and processing of forest inventory data collected from 1,70,000 sampling units distributed all over the country in 1993. The volume present in the each stratum was converted in to stem biomass by multiplying with mean density of that forest composition. Later, the mean stem wood biomass was multiplied with expansion factor to derive the stem or total above ground biomass. The stratum areas were obtained from the satellite data was used for extrapolation. The above ground biomass densities ranged from 14 to 210 Mg ha^{-1} with a mean of 67.4 Mg ha^{-1}, which equals around 34 Mg C ha^{-1} Haripriya (2000).

Swamy and Puri (2002) reported 24.12 to 31.12 Mg ha^{-1} carbon storage in *Gmelina arborea* agroforestry plantations on red laetritic sites in sub humid tropics of Chhattisgarh, India. Schroeder (1992) also reported 8 to 78 Mg ha^{-1} Carbon storage in fast growing plantations of *Acacia mearnsii, Leucaena Spp. Casuarina sp, Cassia siamea* and *Azadirachta indica* in humid tropics. Swamy (1998) observed 94.3 to 190.96 Mg C ha^{-1} in semi-evergreen forests of Karnataka. Kaur et al (2002) studied the carbon storage in 6 year of old silvi pastoral systems on sodic soil in north western India. The total C storage in trees + *Desmostychus* system ranged from 6.8 to 18.55 t C /ha and 1.5 to 12.3 C /ha in case of *Dalbergia sissoo* + *Sporobolus marginatus.* Arora and Chaudhry (2015) was carried out study pertaining to Estimation of vegetation and soil carbon stock of *Populus deltoides* plantation under social forestry scheme in Kurukshetra, Haryana over a period of one year. The plantation had a significant carbon sequestration potential with vegetation carbon stock of 88.45 Mg/ha in different tree components with a carbon flux of 4.6 Mg/ha/yr (Arora and Chaudhry, 2015).

Shankar *et al*., (2014) reported that *Dalbergia sissoo* indicated highest total biomass carbon (254.72 kg per tree), *Acacia nilotica* (228.42 kg per tree), and *Albizia lebbeck* (219.84 kg per tree) in avenue plantations. Jayashree *et al*., (2013) estimated carbon sequestration in four year existing shelterbelts, where *Dalbergia sissoo* showed maximum biomass accumulation of 25.69 ton/ha with carbon sequestration of 12.84 ton/ha. Pandya *et al*., (2013) estimated the carbon storage by non-destructive or allometric method found carbon storage in *Tamarindus indica* 55.95 t C, *Terminalia arjuna* 44.81 t C and 1.77 t C/ha in *Emblica officinalis* trees in Gujarat. Kaul *et al*., (2010) was used dynamic growth model (CO_2-FIX) for estimating the carbon sequestration potential of Sal (*Shorea robusta*), Eucalyptus (*Eucalyptus tereticornis*), poplar (*Populus deltoides*), and teak (*Tectona grandis*) forests in India. As per Kaul *et al*., (2010), the results indicate that long-term total carbon storage ranges from 101 to 156 Mg C ha^{-1}. The net annual carbon sequestration rates were achieved for fast growing short rotation poplar (8 Mg Cha−1yr^{-1}) and Eucalyptus (6 Mg Cha^{-1}yr^{-1}) plantations followed by moderate growing teak forests (2 Mg Cha−1yr^{-1}) and slow growing long rotation Sal forests (1 Mg Cha^{-1}yr^{-1}).

Ahir Balvant (2015) estimated the carbon sequestration potential of *Acacia mangium* plant parts in different diameter classes. In trees with diameter class 30-35 cm carbon in leaves was 52.13 kg/tree, Branch wood 62.14 kg/tree, trunk (228.25 kg/tree) and in roots 62.50 kg/tree while in diameter class below 5cm the carbon in leaves was 0.97 kg/tree, branch wood 0.36 kg/tree, trunk with 3.69 kg/tree and in roots 0.41 kg/tree. Thus it helps to understand the carbon sequestration dynamics by different parts of tree in diameter classes. The references on carbon sequestration potential of agroforestry trees are available but not as such for agroforestry system as a whole to represent the contribution from different agroforestry components (Crop, Shrubs, horticultural crops, fisheries and livestock) which are also integral part of agroforestry. Behera et al. (2015) reviwe suggested that the *Eucalyptus, Albizia procera, acrocarpus fraxinifolius, Ailanthus excelsa Azadirahta indica Cassia siamia Dalbergia sissoo* sequester more carbon within short time, morever rate of carbon sequestration increases with increase in age of the plantaion.

The recent development in agroforestry approach moved ahead of conventional biophysical and ecological focus to more economic criteria for trees rather crops that to not in terms of products but payment for environmental services eg. Carbon credits and carbon finance. Though different pilot studies have been carried out in India in different ecologies but still they were not able to be replicated. Manmohan et al. (2012) reported in Palanakhurd-Nurda-Bhimal grid area of 5000 ha. and 2000 villagers in Mavali block of Rajasthan, India the potential of agroforestry interventions in grid area calculated more than 30000 CERs and with existing two years interventions 5000 CERs to be validated with SMART CDM process. Rajani et al. (2015) reviewed agroforestry based carbon projects in India and revealed that carbon potential of agroforestry (AF) systems has not been reflected in registration of CS projects due to lack of best practices in AF, procedures and methodologies for carbon accounting, etc. They also suggested to develop an appropriate model for payments of environmental benefits specially by studying poplar based AF to understand the process of accounting CS and its practical applicability for environmental payments.

Conclusion

The present paper concludes that the agroforestry systems have diverse potential for C sequestration but need a precise methodology to calculate carbon sequestration potential of every component in the system. The present reviews reflect more role of agroforestry trees or agroforests rather the agroforestry system. A holistic approach with component centric will illustrate more comprehensive potential of agroforestry systems in carbon pool. The young trees association in agroforestry systems can serve not only as C sink but they have more potential to sequester C at faster rate. Therefore, development of new agroforestry models with objective of wider adaptations and cash environment benefits seems to be more purposeful in the years to come. The paper explored the magnitude and potential of agroforestry systems for carbon sequestration in relation to mitigating the global warming and climatic change.

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References

1. Ahir Balvant, R. 2015. “Studies on below ground interaction and carbon sequestration in Acacia mangium willd plantation”. *M.Sc. Forestry Thesis*, Navsari Agricultural University, Navsari, India
2. Arora, P. and Chaudhry, S. 2015. Carbon Sequestration Potential of Populus deltoides plantation under Social Forestry Scheme in Kurukshetra, Haryana in Northern India. *J. Mater. Environ. Sci*., 6 (3): 713-720.
3. Behera, L.K., Nayak, M R, Gunaga, R P, Manmohan J Dobriyal and Jadeja D.B. 2015. Potentality of planted forest towards carbon sequestration and climate change mitigation. *Int. J. of Usuf. Mangt.* 16(1): 82-91.
4. Birdsey, R. A. and Health, L. S. 1995. Carbon changes in US forests. Productivity of America’s Forest and Climate Change (ed. Joyce, L. A.), USDA For. Serv. Gen. Tech. Rep/RM-GTR, 1995, vol. 271, pp. 56–70.
5. Brown, S. and Lugo, A.E. 1982. The storage and production of organic of matter in tropical forests and their role in global carbon cycle. *Biotropica* 14:161-187.
6. Brown, S., Therson, L.R. and Lugo, A.E. 1994. Land use and biomass changes of forests in peninsular Malaysia from 1972 to 1982: A GIS approach. Springes-verlag Jue. U.S. America.
7. Chaturvedi, O.P. and Singh, J.S. 1987. The structure and function of pine forest in central

Himalayas. Dry matter dynamics. *Annals of Botany*. 60:237-252.
8. Davidson, E. A., Trumbore, S. E. and Amudson, R. 2000. Soil warming and organic carbon content. *Nature*, 408, 789–790.
9. Fazakas, Z. and Nilsson, M. 1996. Volume and forest cover estimation over Southern Sweden using AVHRR data calibrated with TM data. *International Journal of Remote Sensing*. 17(9):1701-1709.
10. Goodale, C. L., Apps, M. J. and Birdsey, R. A. 2002. Forest carbon sinks in the northern hemisphere. *Ecol. Appl*., 12, 891–899.
11. Haripriya, G.S. 2000. Estimates of biomass in Indian forests. *Biomass and Bioenergy.* 19:(250):245- 258.
12. Heath, L.S. 2007. Methodology for Estimating Net Carbon Stock Changes in Forest Lands Remaining Forest Lands. In: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005. Unpublished methods documentation on file at the Northern FIA Program, Durham, New Hampshire scheduled for publication by the EPA in 2008.
13. https://www.co2.earth (retrieved on 8th July, 2016)
14. Indu K Murthy, Mohini Gupta, Sonam Tomar, Madhushree Munsi, Rakesh Tiwari GT Hegde and Ravindranath NH. 2013. Carbon Sequestration Potential of Agroforestry Systems in India. *J Earth Sci Climate Change*. 4:1 (http://dx.doi.org/10.4172/2157-7617.1000131).
15. Jayashree, M. K., Nagarajaih, C., Chavhan, G., Kittur, B. H., GavalA. R. and Shivanna, H. 2013. Assessment of carbon sequestration of different tree species planted under shelter belt of northern traditional zone of Karnataka. *Environment & Ecology*, 31 (3): 1231-1234.
16. Kaul, M., Mohren, G. M. J., and Dadhwal, V. K. 2010. Carbon storage and sequestration potential of selected tree species in India. *Mitig Adapt Strateg Glob Change*, 15: 489–510.
17. Kauppi, P. E., Mielikainen, K. and Kussela, K. 1992. Biomass and carbon budget of European forest, 1971–1990. *Science*, 256, 70–78.
18. Kaur B. Gupta S.R. and Singh, G. 2002. Carbon storage and nutrient cycling in silvo pastral systems on sodic soils in northwestern India. *Agroforestry systems*, 54: 21-29.
19. Kirby, K. R. and Potvin, C. 2007. Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. *Forest Ecology & Management*, 246, 208–221.
20. Koskela J., Nygren P., Berninger F. and Luukkanen O. 2000. Implications of the Kyoto Protocol for tropical forest management and land use: prospects and pitfalls. *Tropical Forestry Reports* 22. University of Helsinki, Department of Forest Ecology. Helsinki. 103 pp.
21. Losi, Christopher J., Thomas G. Siccama, Richard Condit, and Juan E. Moralesb. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management,* 184 (1-3): 355-368.
22. Manmohan J.R., L.K. Dashora, S.R. Maloo, and Deepak Sarolia. 2012. Improvement in livelihoods and benefits of small and marginal farmers through Agroforestry interventions with carbon finance *In: Proceedings of National Seminar Agrofoprestry: An evergreen agriculture for food security and environmental resilience*, 2-4 Feb, 2012 at NAU, Navasari, Gujarat.
23. Mishra, R. 1968. Ecology Work Book Oxford and IBH Publishing Co, Calcutta, pp. 244.
24. Nair, P.K.R., Kumar, B.M, and Nair V.D. 2009. Agroforestry as a strategy for carbon sequestration. *J Plant Nutr Soil Sci* 172:10–23.
25. Newaj, R, and Shabir, A.D. 2009. Carbon sequestration potential of different land uses opputunities offered by agroforestry. In. Chaturvedi, O.P., A Venktesh, Rs Yadav, Badri Alam, R.P. Dewedi.
26. Odum, E.P. 1983. Basic Ecology. Saunders College Publishing, Holt Saunders, Japan, 613.
27. Pandya, I. Y., Salvi, H., Chahar, O. AND Vaghela, N. 2013. Quantitative analysis on carbon storage of 25 valuable tree species of Gujarat, incredible India. *Indian J. Sci. Res*, 4 (1): 137-141.
28. Rai, S.N. 1984. Bole, branch, current year twig, leaf and root biomass production in tropical rain (wet evergreen) forests of Western Ghats of Karnataka. *Indian Forester* 110(9):901-913.
29. Rajni Sharma, Sanjeev K. Chauhan , Abhishek M. Tripathi. 2015. Carbon sequestration potential in agroforestry system in India: an analysis for carbon project. *Agroforestry Systems* pp 1-14 First online: 23 August 2015.
30. Reves, D. W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res*., 43, 131–167.
31. Sanchez, P. A. 2000. Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystem and Environment*, 82, 371–383.
32. Schroeder, P. 1992. Carbon storage potential of short rotation tropical tree plantations. *Forest Ecology and Management* 50:31-41.

33. Shamsudheen M, Devi Dayal, S. L. Meena and Bhagirath Ram (2014) Carbon sequestration in agroforestry and pasture systems in arid northwestern India. *Current Science*, Vol. 107, No. 8, 25 October 2014.
34. Shankar, R., Naresh, D., Joseph, B. and Suneetha Devi K.B. 2014. Carbon sequestration rate, carbon storage rate and biomass estimation in major multipurpose agroforestry tree species in destructive method. *International J. of Scientific Research*, 3 (10): 2277 – 8179.
35. Sharma, E., Rai, S.C. and Sharma, R. 2001. Soil water and nutrient conservation in mountain farming system. Case study from the Sikkim Himaya. *Journal of Environmental Management*, 61: 123-135.
36. Sharma, P. 2003. Ecological Linkages of Carbon Dynamics in Relation to Land-Use / Cover Change in a Himalayan Watershed. *Ph.D. Thesis,* University of North Bengal, India.
37. Sharma, R. 1995. Symbiotic Nitrogen Fixation in Maintenance of Soil Fertility in the Sikkim Himalaya. *Ph.D. Thesis*, H.N.B. Garhwal University, India.
38. Shepherd, D. and Montagnini, F. 2001. Above ground carbon sequestration potential in mixed and pure tree plantations in the humid tropics. *Journal of Tropical Forest Science* 13(3):450-459.
39. Shukhdev, P., Prabhu, R., Kumara, P., Bassic, A., Patwa-Shaha, W., Entersa, T., Labbatea, G. and Julie, G. 2015. REDD+ and a Green Economy: Opportunities for a mutually supportive relationship. UN-REDD Programme Policy Brief 01.
40. Smith, J. E., Heath, L. S., Nichols, M. C. 2007. U.S. forest carbon calculation tool: forest-land carbon stocks and net annual stock change. Gen. Tech. Rep. NRS-13. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 28 p.
41. Smith, J.E., Heath, L.S. 2002. A model of forest fl oor carbon mass for United States forest types. Res. Pap. NE-722. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 37 p.
42. Swamy, S.L. 1998. Estimation of Net Primary Productivity (NPP) in an Indian tropical evergreen forest using Remote Sensing data. *Ph.D. Thesis*, Jawaharlal Nehru Technology University, Hyderabad, India.
43. Swamy, S.L. and Puri, S. 2002. Growth, biomass, carbon storage and nutrient distribution in *Gmelina arborea* Roxb. Stands on red lateritic soils in central India. Bioresource Technology 3, 135.
44. Tiwari, A.K. 1994. Mapping forest biomass through digital processing of IRS-1A data. *International Journal of Remote Sensing* 15(9):1849-1866.
45. Tiwari, A.K. and Singh, J.S. 1984. Mapping forest biomass in India through aerial photographs and non destructive field sampling. *Applied Geography*.4:151-165.
46. Wilson, B. R.S.A. and Daff, J.T. 2003. Australia's State of the Forest Report. Department of Agriculture, Fisheries and Forestry, Government of Australia.

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