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ORIGINAL PAPER

Development of an agroforestry carbon sequestration project in Khammam district, India

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Abstract This paper addresses methodological issues in estimating carbon (C) sequestration potential, baseline determination, additionality and leakage in Khammam district, Andhra Pradesh, southern part of India. Technical potential for afforestation on cultivable wastelands, fallow, and marginal croplands was considered for *Eucalyptus* clonal plantations. Field studies for aboveground and belowground biomass, woody litter, and soil organic carbon for baseline and project scenarios were conducted to estimate the carbon sequestration potential. The baseline carbon stock was estimated to be 45.3 t C/ha, predominately in soils. The additional carbon sequestration potential under the project scenario for 30 years is estimated to be 12.8 t C/ha/year inclusive of harvest regimes and carbon emissions due to biomass burning and fertilizer application. Considering carbon storage in harvested wood, an additional 45% carbon benefit can be accounted. The project scenario has a higher benefit/cost ratio compared to the baseline scenario. The initial investment cost requirement, however, is high and lack of access to investment is a significant barrier for adoption of agroforestry in the district.

Keywords Climate mitigation · Afforestation · Aboveground biomass · Soil organic carbon · Baselines · Leakage

1 Introduction

Globally, forestry has taken center stage as one of the options to mitigate climate change. Total global technical potential for afforestation and reforestation activities for the period 1995–2050 is estimated between 1.1 and 1.6 Gt C/year, of which 70% potentially would occur in the tropics (IPCC 2000). Agroforestry is an attractive

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option for carbon (C) mitigation as (i) it sequesters carbon in vegetation and soil, depending on the pre-conversion vegetation and soil carbon; (ii) wood products produced serve as substitutes for similar products that are unsustainably harvested from natural forests; and (iii) it increases income to farmers (Makundi and Sathaye 2004). Approximately 1.2 billion people, 20% of the world's population, depend directly on agroforestry products and services in rural and urban areas of developing countries (Leakey and Sanchez 1997).

The potential land area suitable for agroforestry in Africa, Asia and the Americas has been estimated at 585–1215 Mha (Dixon 1995). An additional 630 Mha of current croplands and grasslands could be converted into agroforestry, primarily in the tropics, via of two types of agroforestry activities: converting fallow and marginal croplands to agroforestry, and adopting agroforestry practices into existing cropping systems.

A large potential for agroforestry has given rise to scientific and policy questions from national governments, climate change negotiators, potential investors in greenhouse gas mitigation activities and local communities. The contentious issues are (1) additional carbon that could be created, (2) magnitude of emissions reductions that can be achieved, (3) cost-effectiveness and total cost for implementation of agroforestry projects, and (4) institutional arrangements. To research some of these issues, this paper considers agroforestry options in Khammam district, Andhra Pradesh, in southern India. The paper's main objectives are to:

– Estimate carbon sequestration potential of farm forestry plantations promoted by industry,
– Develop baselines for farm forestry plantation projects,
– Establish additionality of carbon sequestration for farm forestry activity,
– Measure carbon stock changes through the stock change approach, and
– Assess leakage and measures to address leakage.

2 Description of project location

The Khammam district lies in the northeastern part of the state of Andhra Pradesh, located between 17°40′ N and 81°00′ E, and rises 100 m above mean sea level. Forest area constitutes 52% of the district geographic area and the forest types are tropical moist deciduous, tropical dry deciduous and tropical thorn. Soils in the region are of black cotton, red alluvial loam and red sandy type.

The study was conducted in six mandals,[1] in the Khammam district, namely Burgampahad, Kukunoor, Bhadrachalam, Kunavaram, Cherla and Velairpadu. The study area comprises 13% of the district area. The land use pattern in the mandals is given in Table 1. Forests dominate land use, and account for 62% of the geographic area. Cultivated agricultural lands form the second most abundant landuse with a mean cropping area of 18%, followed by non-agricultural lands (8%). The rest of the area is covered by barren and uncultivated land (4%), fallow land (1%), and land under tree crops, pasturelands and cultivable waste each less than 1%.

[1] Mandal: Administrative unit below the district consisting of a group of villages/panchayats. In Andhra Pradesh blocks were subdivided into mandals but retained the administrative and local government functions of blocks (http://www.velugu.org/faq.html).

Table 1 Land use pattern in the six selected mandals of Khammam district, Andhra Pradesh (ha)

Land uses	Burgampahad	Kukunoor	Bhadra-chalam	Kuna-varam	Cherla	Velair-padu	Total
Geographic area	27,390	28,681	37,669	20,382	54,337	41,544	210,003
Forest cover	14,609	17,067	25,514	5,435	37,478	29,471	129,574
Total cropped area	7,596	4,835	9,770	6,089	6,715	3,184	38,189
Misc. tree crops	208	277	48	315	163	218	1,229
Non-agriculture land	1,311	1,627	2,015	4,364	5,446	2,694	17,457
Pasture & grazing	284	297	0	19	0	236	836
Barren & uncultivated	624	902	159	2,128	3,499	709	8,021
Cultivable waste	28	166	0	139	63	500	896
Other fallow land	101	1,056	54	0	264	612	2,087
Total	24,761	26,227	37,560	18,489	53,628	37,624	198,289

Croplands vary in the mandals, but have identical management practices with regard to application of chemical fertilizers and irrigation practices. The cropping pattern in the six selected mandals in Khammam district is dominated by rice (*Oryza*) (38%), except in Bhadrachalam and Kunnavaram mandals (Table 2). Cotton (*Gossypium*) is the second largest crop with 16% of the cropping area, followed by chilli (9%) jowar (9%) and redgram (8%). The rest of the cropping area (19%) includes green gram, sugarcane, maize (*Zea*), black gram, tobacco (*Nicotiana*), groundnut and sesamum. Farm forestry accounts for only 10% of the cultivated area in these mandals. *Eucalyptus* and *Luceana leucocephala* clones form 90 and 3% of the area, respectively, and the remaining plantations are raised by the Andhra Pradesh Forest Department (7%).

3 Afforestation rates—past and projected

Past, current and projected rates of afforestation and reforestation (A&R) are considered in projecting the "business as usual" or baseline scenario, and the potential for farm forestry project activities in the selected mandals. In this region, agroforestry is being promoted largely by ITC (a large national paper products company operating a paper mill at Bhadrachalam), and the rate of afforestation was about 54 ha/year during the period 1992–1999 (Table 3). The rates increased 5-fold

Table 2 Cropping pattern in the selected mandals (ha)

Crops	Bhadrachalam	Burgampahad	Kunavaram	Kukunoor	Cherla	Velairpadu	Total
Paddy	2,762	2,569	1,447	1,812	3,220	774	8,590
Jowar	996	53	1,942	56	0	0	3,047
Maize	121	60	14	72	0	0	267
Greengram	190	266	404	150	692	227	1,010
Blackgram	288	48	998	331	126	0	1,665
Sugarcane	0	2	0	54	54	46	56
Redgram	1,319	434	182	395	287	148	2,330
Cotton	1,157	3,046	97	1,008	0	67	5,308
Tobacco	517	115	492	81	0	0	1,205
Chillies	1,955	273	377	348	7	120	2,953
Groundnut	99	81	1	0	197	197	181
Sesamum	190	94	96	18	0	0	398
Total	9,594	7,041	6,050	4,325	4,683	1,578	27,010

Table 3 Area afforested under farm forestry in selected mandals of Khammam district (ha)

Mandal	Bhadra-chalam	Burghampahad	Kuna-varam	Kukunoor	Cherla	Velair-padu	Total
1992–1999	312	60	49	9	2	4	429
2000	76	17	36	6	10	2	136
2001	101	14	33	30	0	1	179
2002	126	83	74	54	0	0	338
2003	143	36	63	31	,7	9	273
2004	154	54	51.2	12	0.0	0	272
Total	912	265	308	142	19,5	9	1,627
Average planting rates (2000–2004)	120	41	52	27	3	2	240

Note: areas are rounded to nearest ha

to about 240 ha/year during 2000–2004 (Table 3). The company intends to plant 364 ha/year in the next 6 years (2005–2010) in these six mandals.

3.1 Technical potential of land for afforestation

The farmers are currently converting land under crops such as chilli, cotton and redgram to plantations. Though the yearly land use change pattern is not available, discussion with the farmers reveal the preference of farmers to shift from crop cultivation to Eucalyptus plantation. Just considering uncultivated lands such as pasture land, cultivable and fallow land, 9,658 ha are available after deducting the projected afforestation rates by the ITC company for the period 2005–2010 to estimate additional ha above the baseline. Thus the land potential for agroforestry is significant, considering conversion of marginal croplands, the current practice.

4 Additionality

A project activity is additional if anthropogenic emissions of greenhouse gases by sources are reduced below those that would have occurred in the absence of the project activity—the baseline. Additionality tests vary by greenhouse gas (GHG) mitigation program (e.g., the UNFCCC's Clean Development Mechanism (CDM), but conceptually a project needs to demonstrate environmental, technical and financial additionality. A project's environmental additionality is determined by the comparison of baseline and project GHG-benefits. The proposed project activities should: (a) result in increase of net carbon stocks, (b) would not have gone ahead (or not in their proposed form) in the absence of the project, and (c) do not result in increased deforestation (or decreased carbon removals) elsewhere (known as leakage). Further, in the case of the CDM, the project should contribute to sustainable development, e.g., via local socio-economic benefits such as increased employment, income or access to non-timber forest products. Financial additionality requirements in the CDM include both a macro additionality factor, i.e., not financed with the help of Official Development Assistance (ODA), and the micro additionality factor or investment additionality.

One approach is use of the additionality tool developed by the UNFCCC (www.cdm.unfccc.int/methodologies/PAmethodologies), which requires demonstrating the following:

- *Identify likely alternative land use project activities*: The alternative to the project is dryland agriculture or status quo. Crops such as cotton, chilli and tobacco can be cultivated on these lands or can remain fallow.
- *Identify investment options*: Clonal Eucalyptus plantations require a high establishment cost for the initial 3 years. Farmers have to invest Rs. 40,000/ha (about $890 US at exchange rate of $1 US = Rupees 45) for raising Eucalyptus plantations. Financial institutions do not extend loans for plantations due to the risk factor, and funding from international sources is lacking. The alternative to the project, continued agriculture, is easier to adopt due to loan availability from banks and other financial organizations.
- *Analysis of barriers*: As mentioned above, finance is a barrier since loans cannot be secured from national and international markets for afforestation and the investment required is high.
- *Analysis of usual practice*: This step is to identify similar projects in terms of geographical area, technology, size and access to financing and differentiate them from the proposed project. In Khammam district, most of the rich farmers with large landholdings plant part of their agricultural land with the Bhadrachalam Eucalyptus clones, which should be incorporated into the baseline. The farmers pay upfront for the seedlings and other establishment costs. Under the project scenario, small and marginal farmers with small landholdings could be identified and planting performed on their lands. The impacts of such a project beyond environmental benefits would be to attract new investors.

5 Baseline development

Baseline estimation guidance is not yet standardized. Under the U.N. Framework Convention on Climate Change's Clean Development Mechanism (CDM), for example, "the baseline for project activity is the scenario that reasonably represents anthropogenic emissions by sources of GHGs and removal by sinks that would occur in the absence of the proposed project activity". In this case, a structured project-specific approach to baseline development was adopted, based on reliable, site-specific information and comprehensive analysis, with the potential to credibly quantify additionality. Site-specific data were used to calculate the initial stock of carbon as climatic and site conditions, species planted and site management all significantly can affect the carbon content of different management systems. Socio-economic indicators and land suitability were examined while assessing the most likely land use for a project site, as they are important determinants of land use, These factors can vary from site to site. The general approach used to estimate the baseline was to:

1. Identify current land use/land use trends and associated carbon stocks of the project site;
2. Assess likely future land use without intervention planned in the project case; and
3. Quantify carbon uptake and emissions of likely land use over the project life.

The following steps were undertaken to establish the baseline (Ravindranath et al. 2006):

- Define land use systems and their tenurial status;
- Define the project boundary and prepare a map;
- Select carbon pools and define methods for measurement;
- Develop sampling design and strategy for biomass and soil carbon estimation;
- Lay plots in different land use systems and measure identified parameters;
- Analyze data for aboveground biomass (AGB) carbon stock, belowground biomass, woody litter, dead wood and soil carbon;
- Assess past and current A&R rates;
- Project future land use and estimate potential area for the project activities; and
- Estimate carbon stocks using area and per ha carbon stock data, for the project area.

5.1 Project area and legal status

The project activity—afforestation—is proposed on cultivable wastes, marginal crop and fallow lands in the six mandals of Khammam district. These lands are legally under private ownership of individual farmers.

Cultivable waste (long fallow) lands are available for cultivation, but not cultivated during current year and last 5 years or more in succession. Such lands may be either fallow or covered with shrub and jungle, and are not put to any use (NRSA 1995).

Fallow lands are lands temporarily out of cultivation for a period of not less than 1 year and not more than 5 years, due to: (i) poverty of cultivators, (ii) inadequate supply of water, (iii) silting of canal and rivers, and/or (iv) the non-remunerative nature of farming (NRSA 1995).

5.2 Project boundary

The project boundary needs to encompass all anthropogenic emissions by sources of GHGs and removals by sinks under the control of the project participants that are significant and reasonably attributable to the project activity, in the case of the CDM rules. The project area consists of geographic domain with more than one discrete area of land, within which GHG emissions or removals and other attributes of a project are to be estimated and monitored. Thus the six mandal boundaries are the project areas. The project boundary includes discrete blocks of plantations on individual farmer's lands in each of the mandals.

5.3 Sampling strategy for baseline

The carbon pools selected for baseline development are aboveground biomass, belowground biomass, and soil organic carbon. Dead wood was not included as this was not a major carbon pool under farm forestry. The definitions of carbon pools are as defined by the IPCC (2003).

5.3.1 Aboveground and belowground biomass

This dominant carbon pool was estimated by the commonly used plot method. Sampling on farmlands involved enumeration of all trees on individual farms. Sampling strategy for farm forestry involved randomly selecting 10 farmers who were open to farm forestry activity with Eucalyptus clones, of which five were small farmers (<2 ha) and five were large (>2 ha). A total of 40 farmers were selected and interviewed to assess the cost and benefits of the present crop and the area available for farm forestry. A total of 95 ha of fallow and culturable wasteland owned by them was sampled. All trees >1.5 m in height or >5 cm DBH (Diameter at Breast Height) were enumerated. Species-specific or generic volume equations from Forest Survey of India (FSI) reports (1996) were used to convert DBH and height into volume (m^3/ha), and a coefficient of 0.45 of biomass was used to estimate carbon content. A default conversion factor of 0.26 of aboveground biomass was used to calculate the belowground biomass (IPCC 2003).

5.3.2 Soil carbon

To estimate soil organic carbon, soil samples at depths of 0–15 and 15–30 cm were collected. Bulk density was measured and soil organic carbon content was estimated in the laboratory using the Walkley–Black method. Soil samples from tree plots in marginal agricultural lands and other fallow lands representing baseline scenario were collected. A composite soil sample from multiple soil samples was prepared for different land categories.

5.4 Determination of the baseline

The features of the project land area are:

- These lands have not been forested since 1990 and have either been croplands or fallow since then;
- The identified lands in the project area consist of cultivable wastes, fallow lands and marginal croplands; and
- Thus the current land use is either agriculture or fallow lands.

5.4.1 Biomass stock under baseline scenario

The aboveground biomass under baseline scenario is comprised of trees that are planted on bunds[2] of agricultural lands. In the sampled area of 95 ha of farmlands, the aboveground biomass varied from nil to 0.19 t/ha, with an average aboveground biomass of 0.02 ± 0.05 t/ha. Considering 0.26 as the conversion factor for estimating belowground biomass from aboveground biomass, 0.005 t//ha accounts for the belowground biomass. There was negligible woody litter. Thus the total biomass under baseline is 0.025 t/ha in the project area—an extremely low baseline C value.

[2] Earthen embankment constructed to retain water or for separating one farm from another.

5.4.2 *Soil organic carbon (SOC) under baseline scenario*

Land use history has a strong impact on the SOC pool. Ecosystem studies of soil carbon indicate large differences in soil carbon depending on soil type, topography, land-use history, and current land use and land cover (Marland 2004). The SOC varies depending on agricultural systems and crops and on the inputs to production (e.g., fertilizers, irrigation and soil tillage). Therefore the SOC content of marginal cropland and fallow lands were determined in the proposed project area for depths of 0–15 and 15–30 cm.

In the proposed project area, the SOC for black and red soil under marginal croplands and fallow lands was determined. Black cotton soil was prevalent in the mandals of Bhadrachalam and Kunnavaram and red sandy and alluvial soil in Burgampahad and parts of Kukunoor mandal. The agricultural system and the inputs to production were similar with fertilizer application, irrigation and soil tillage by all the farmers. The average SOC at 0–30 cm depth of black soil was 47.0 ± 15.9 t/ha and for red soil 37.1 ± 16.9 t/ha. Further analyzing at different soil depths, the deviation was low at 0–15 cm layers than at 15–30 cm level (Table 4). Aggregation of homogeneous land use systems provides a regional baseline for Khammam district SOC of 45.3 ± 16.0 t/ha.

5.5 Carbon stock changes under baseline

Carbon stocks in the baseline on fallow or marginal cropland of aboveground biomass is 0.02 t/ha due to a few big trees on the bunds, with an average DBH of >40 cm, but with negligible growth, since they have reached equilibrium.

The soil C status under the pre-plantations land use is assumed to be in approximate equilibrium with inputs equals to outputs. If land has been cultivated for decades, the rapid soil C changes with initial cultivation would have ceased, and either soil C is changing very slowly or has stabilized. Thus, the carbon stock change under baseline can be considered static. The C-stock under baseline is 45.3 t/ha, which could continue to remain so under the baseline scenario. For a project area of 8,000 ha, the baseline C-stock would remain constant at 362,000 t C.

Table 4 Soil organic carbon (t/ha) by depth in cropping systems and soil types in Khammam district, based on field studies

Management practice	Soil type	Soil organic carbon (t\ha) at different depths		
		0–15 cm	15–30 cm	0–30 cm
Chilli	BS	26.8 ± 2.7	20.7 ± 9.4	47.5 ± 11.2
Cotton	BS	27.9 ± 8.0	20.1 ± 14.9	47.9 ± 20.1
Miscellaneous	BS	21.0 ± 5.4	18.3 ± 9.2	39.3 ± 3.8
Fallow	BS	31.6 ± 10.0	18.6 ± 13.8	50.2 ± 23.8
Average	BS	27.2 ± 6.9	19.8 ± 11.6	47.0 ± 15.9
Miscellaneous	RS	16.6 ± 4.3	20.5 ± 13.3	37.1 ± 16.9
Average	BS + RS	25.4 ± 7.6	19.9 ± 11.5	45.3 ± 16.0

Notes: BS = Black Soil (Vertisols); RS = Red Soil (Alfisols)

6 Project activities

6.1 Area for project activities

The land categories considered for afforestation are pasture and grassland, barren and uncultivated, cultivable waste and fallow land use in the six selected mandals, totaling 10,687 ha. Of them, 8,000 ha are identified for AR from cultivable waste, fallow and marginal croplands on private farmland, through planting Bhadrachalam Eucalyptus clones at a rate of about 2,000 ha/year.

6.2 Lifetime of the project

The lifetime of the project is defined by technical or economic considerations and is generally longer than the period during which the carbon credits can be legitimately generated (FA 2005). The lifetime of the project is assumed to be seven or eight rotations or approximately 30 years, i.e., 2006–2035. The PROCOMAP model (Sathaye et al. 1995) is used to account for annual changes in carbon stock for the project period of 30 years. The accounting period is a determining factor for the volume of emission reductions that can be generated by a mitigation project.

6.3 Sampling strategy for project scenario

The AGB, BGB, SOC and woody litter pool carbon stocks and growth rates were measured in the same or neighboring villages with plantations, and estimated as inputs to PROCOMAP to project likely C-stocks for the project activities over 30 years.

6.3.1 Aboveground biomass

AGB was determined by two-pronged strategy that included (a) monitoring in permanent plots, and (b) direct AGB measurements by harvest. Permanent plots of Eucalyptus clones that represent the project scenario are being measured twice a year for their annual increments in AGB by the paper mill company, providing 9 years of annual data for Current Annual Increment (CAI), Mean Annual Increment (MAI) and Eucalyptus-specific volume equations. The harvest method is the most accurate of all the biomass estimation methods since it involves direct measurement of methodically harvested tree components. This avoids the usual inadequacies of equation-based methods, viz., unavailability of specific equations and the valid range of these equations for accurate results, variability in area of sampling and area measured in the equations, and manual errors. The biomass expansion factor was calculated by the above procedure (excluding the BGB) at private farmlands where Eucalyptus was commercially harvested.

6.3.2 Belowground biomass

The belowground biomass is by far the most uncertain of the carbon pool biomass estimates, even though IPCC (2003) provides a conversion factor of 0.26 of the aboveground biomass. In this study, the harvest method was used.

6.3.3 Soil carbon

Soil samples at depths of 0–15 and 15–30 cm were collected from ploughed and unploughed sites, and analyzed using the Walkley–Black method. SOC was determined for 0–30 cm depth on a per-hectare basis.

The soil type was stratified into red and black soil, and then further stratified by land use or crop type for the baseline scenario. For the project scenario, soil samples were collected from different age classes and from adjacent land, which served as the control. The difference of SOC was taken as the increment over the age class. For each of the age class, weighted average of SOC was calculated, for a composite of soils from tilled and untilled lands.

Eucalyptus plantations are regularly tilled after the rains every year, and fertilizers such as urea, MOP and DAP are applied annually. The weighted average for various plantation age classes was computed, and the difference in increment from the subsequent age class was considered the annual SOC increment, and projected out for the regional baseline scenario (Fig. 1).

6.4 Carbon accumulation in various pools

The PROCOMAP model was used to analyze the mitigation potential as well as cost-effectiveness of mitigation activities. The model estimates change in C stock annually under the baseline and mitigation scenarios. Adopting the C stock change method to estimate the C pool increment mathematically, the change in carbon stocks attributable to a project (ΔCnet) at any given time can be expressed as:

$$\Delta\text{Cnet} = \sum_{i=1}^{n}\big[(\Delta\text{Cproject} - \Delta\text{Cbaseline})_{\text{time1}} + (\Delta\text{Cproject} - \Delta\text{Cbaseline})_{\text{time2}} + \cdots(\Delta\text{Cproject} - \Delta\text{Cbaseline})_{\text{time}n}\big]$$

where ΔCproject and ΔCbaseline are the measured changes in carbon stocks at periodic monitoring time over the period *i*, associated with the project and the respective baseline case.

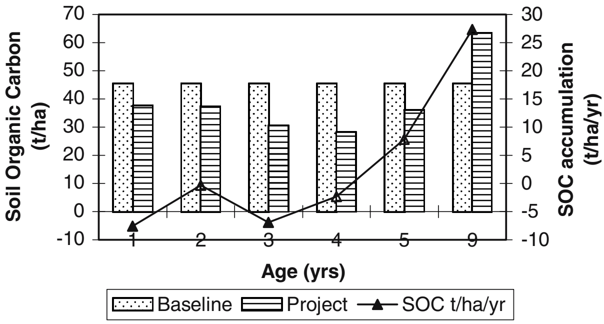

Fig. 1 Carbon stock change in the baseline and project scenario

6.4.1 Aboveground biomass

Based on field measurements in permanent experimental plots maintained by ITC Bhadrachalam paper mills, the CAI of clonal Eucalyptus for pulpable wood (under bark) during years 1–4 is given in Table 5. Field studies were conducted to estimate the ratio of pulpable wood to the total aboveground biomass. The biomass expansion factor ranged from 40.3 to 52.7% of the pulpable wood. Applying the biomass expansion factor and the moisture content, the dry weight of CAI values was estimated (Table 5). Thus, for a 4-year rotation cycle, the total AGB was 40.7 t/ha with a MAI of 10.2 t/ha/year.

6.4.2 Belowground biomass

The overwhelming proportion of the total root biomass is generally found within 30 cm of the soil surface. Measuring the amounts of biomass in roots and their turnover is an extremely costly exercise. Therefore, regression equations are often used to extrapolate aboveground biomass to whole-tree biomass (Kurz et al. 1996; Cairns et al. 1997). The problem with this approach is that deforestation and harvests (as well as changing environmental factors) may change the relationship between aboveground and belowground biomass. On the other hand, belowground carbon might still be assessed from a known history of aboveground vegetation. During the field studies, BGB through harvest method was estimated for years 1–5 age classes (Table 6). The BGB has been assumed to accumulate until the eighth year at the same ratio as that determined for the first rotation, when equilibrium is reached. For years 5–8, the same proportional increase as that of the first rotation (4 years) has been assumed.

Table 5 Aboveground and belowground biomass growth rates of Eucalyptus clone for a 4-year rotation cycle in Khammam district

Parameters	Year 1	Year 2	Year 3	Year 4
Current annual increment of pulpable wood (cubic metres)[a]	12	18	48	24
Wood density	0.55	0.55	0.55	0.55
Annual increment of pulpable wood (t/ha)[b]	6.6	9.9	26.4	13.2
Biomass expansion factor (%)[c]	52.7	47.5	44.4	40.3
Wet weight of aboveground biomass (t)	10.1	14.6	38.1	18.5
Annual Increment of aboveground biomass (dry wt t/ha)[d]	5.0	7.3	19.1	9.3
Total standing biomass (dry wt t/ha)	5.0	12.3	31.4	40.7
Belowground biomass conversion factor (%)[e]	26.8	26.8	26.8	26.8
Belowground biomass (dry wt t/ha)	1.4	3.3	8.4	10.9
Total biomass increment (t/ha/year) (AGB + BGB)	6.4	9.3	24.2	11.7
Total biomass accumulation (t/ha) (AGB + BGB)	6.4	15.6	39.8	51.6

[a] Pulpable wood is under bark, excluding branches, twigs, leaves and bark

[b] Calculated as CAI × wood density

[c] Ratio of branches, twigs, leaves, bark to pulpable wood

[d] Moisture content is 50%

[e] Ratio of belowground biomass to aboveground biomass based on harvest method

Table 6 Belowground biomass as percent of aboveground biomass and woody litter of Eucalyptus clones in Khammam district

Age	Belowground biomass as percent of aboveground biomass	Age	Woody litter (dry wt t/ha/year)
2	36.1	1	0.009 ± 0.010
3	22.4	2	0.026 ± 0.020
4	26.6	3	0.071 ± 0.006
5	22.2	4	0.137 ± 0.036
Average	26.9	Average	0.069 ± 0.060

6.4.3 Woody litter

Based on field studies, the woody litter (dry wt) per year ranged from 0.009 t/ha/year during year 1 to 0.137 t/ha/year in year 4 (Table 6), but is not a major carbon pool in the project area.

6.4.4 Soil carbon stock

A wide variation in changes in soil C is observed following afforestation in the project area, as Fig. 1 demonstrates. Based on field studies conducted in this region, the soil C is likely to be lost during the initial years of plantation establishment. The soil C under the pre-plantation land use is assumed to be in equilibrium with inputs equaling outputs. From year 1 to 4 there has been loss of SOC, while from age 5 to 9 there has been a steady increase in soil C. Thus, the calculations show an initial loss of soil C under plantations with inputs finally exceeding outputs to soil C beginning at year 5. This is in concurrence with results of Hansen (1993).

6.5 Carbon stock change under project scenario

6.5.1 Carbon stock change per ha

The carbons stock change for the project scenario is given in Fig 2. The stock change under the baseline scenario is nearly stable. The C-stock change in project scenario is inclusive of periodic harvest at every 4 years and carbon emissions due to biomass burning after harvest and annual fertilizer application. The carbon emissions due to biomass burning and fertilizer application are given in Table 7. In the initial 4 years, there is carbon emission from soil, after which there is a steady increase above

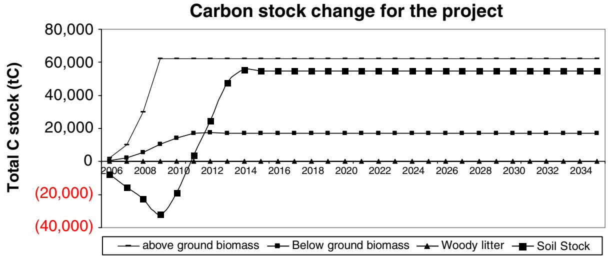

Fig. 2 Carbon stock change in the four carbon pools in project scenario

Table 7 Carbon emissions (t C) due to project activity per rotation cycle

	Year			
	1	2	3	4
C emissions from on-site burning (ha)	0.00	0.00	0.00	4.94
C released from fertilizer application (ha)	0.02	0.09	0.09	0.14
Total C emissions for the project area	45	243	441	10,618[a]

[a] The emissions for years 5–30 are also assumed to be 10,618 t C/year

Table 8 Carbon stock change under project scenario (per ha), 2006–2035

	2006	2011	2016	2021	2026	2031	2035
Baseline	45.3	45.33	45.33	45.33	45.33	45.33	45.3
Project[a]	42.9	61.83	64.04	65.43	65.02	61.30	61.3
C increment	–2.4	16.5	18.7	20.1	19.7	16.0	16.0

[a] The C-stock is estimated after deducting emissions from; biomass burning after harvest and fertilizer application

pre-plantation levels from the seventh year (Table 8). The carbon stock reaches the maximum of 65.4 t C/ha during 2013 providing a carbon increment of 20.2 t C/ha (Table 8).

6.5.2 *Carbon stock change for project area*

The carbon stock change in the project scenario is given in Fig. 2. The mitigation potential for an area of 8,000 ha is 3,077,819 t C at a rate of 384 t C/ha for the period 2006–2035, which is approximately 12.8 t C/ha/year inclusive of harvest regimes and carbon emissions due to biomass burning and fertilizer application. In terms of carbon pools, during the first 5 years there is a loss in soil organic carbon, after which in the next 4 years there is a steady increase to a plateau. The other carbon pools of ABG, BGB and woody litter show a steady rise and after a time period a plateau is reached (Fig. 3). The carbon stock change under different scenarios—with and without wood products—are given in Fig. 3. In the project site, the Eucalyptus wood is used for making pulp for paperboard. The product life is taken as 2 years.

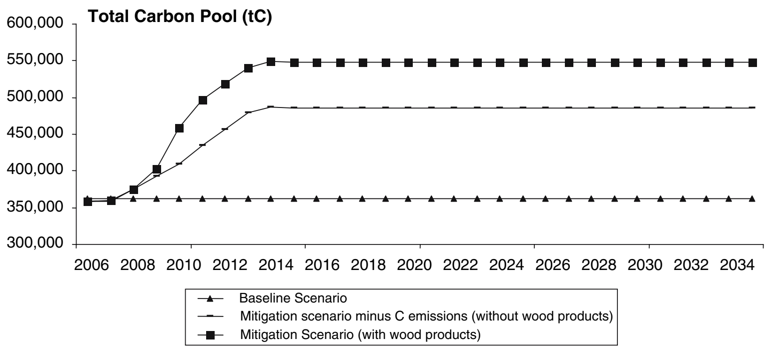

Fig. 3 Carbon stock change with and without wood products under project scenario

Considering C storage in harvested wood, an additional 45% carbon benefit can be accounted. Thus the policy decision to include wood products or not would make a considerable difference to C calculations. One inevitable consequence is that plantations come out as poor performers from a carbon sequestration standpoint alone compared to no-harvest forests, but the economic benefits of wood products also must be considered. The harvested products might be difficult to measure and monitor, adding possibly levels of uncertainty to project accounting procedures. But wood products are a major C pool not to be ignored, and often may be a large carbon sink benefit for plantation projects (Leach 2002).

7 Leakage estimation

Leakage can be defined as the net change of anthropogenic emissions by sources of GHGs and removal by sinks, which occurs outside the project boundary, and which is measurable and attributable to the project activity (UNFCCC 2002). Leakage can occur through shifting activities from the project site to another area, referred to as primary leakage. Secondary or market leakage also can occur where a project's outputs create incentives to increase GHG emissions elsewhere. Primary leakage in the project area can be due to shift in extraction or land use change. Forest conversion to cropland is unlikely, since it is legally banned in the state.

In this study, an attempt was made to estimate leakage through a household survey where the quantity of fuelwood and poles/small timber currently extracted from forests, community grazing land and farmlands proposed for the project is quantified. Based on questionnaire methods, interviews were conducted with farmers who currently have fallow lands and are willing to plant trees on their farmland, and of farmers who currently have plantations. Their current dependence on lands proposed for plantations and forests for fuelwood, poles, and other biomass needs were assessed. Fully 100% of farmers interviewed depended on natural forests for fuelwood and other biomass needs—even those who had plantations. In the project case there would be a new source of biomass available from plantations, especially during harvest every 4 years that can relieve farmer harvest of biomass in natural forests. Further, the baseline standing biomass on farmlands before project activity is negligible, so there is minimal market or non-market activity to displace outside the project area.

Thus, the survey indicates zero leakage from these marginal lands, since they supply no commodities whose extraction would be displaced to other lands. If the project produces plantation products sold in a market that displace plantations being planted elsewhere, then the project's carbon benefit would need to be reduced by the C displaced. The new plantations will not lead to changes in market behavior or area of plantation elsewhere, as these plantations are predominantly sold to ITC for pulp due to favorable market prices.

8 Estimates of cost-effectiveness of project activities

Cost estimates are required to compare forestry projects and link to policies aimed at reducing greenhouse gas emissions. Cost estimates for forestry projects vary greatly according to the methodology employed. Some estimates of carbon sequestration take into account only the commercial component of the tree (or bole), while others include all vegetation. Still others include soil organic carbon (SOC), which can be enhanced through carbon-fixing roots and fallen and decaying branches and leaves, and deteriorated through erosion. The decision to include or exclude SOC alone can result in a vastly different estimate of carbon uptake costs, since as much as two-thirds of the carbon stored in terrestrial ecosystems is in soils (Dudek and LeBlanc 1990).

In this case study, the following approach is adopted:

- The financial method has been employed to determine costs of carbon sequestration;
- The costs of carbon sequestration include establishment costs of plantations and yearly fertilizer application and other activities;
- Costs for determination of baseline have been included;
- Project monitoring is considered as a continuous assessment of the functioning of project activities, and the costs of monitoring are included in the implementation and management costs;
- Transaction costs have been excluded; and
- The benefits include the market price offered to the farmers by ITC Bhadrachalam paper mill, inclusive of harvest and transportation cost.

The costs and benefits of Eucalyptus plantations for a rotation cycle are given in Appendix Table 10. The investment cost is considered for the first 3 years, with the assumption that the community or farmer will meet the annual or operating cost of later rotations. Investors, donors or banks likely to be interested in funding or lending only the investment cost may be guided by these values. The present value of investment cost, extended over the first 3 years, is Rs. 37,856/ha at a discount rate of 6% (or $841 US at 45 Rs./$). The present value of initial cost is Rs. 98/t C.

Often, funding only the investment cost may not sustain a project, so it becomes essential to consider annual or operating or maintenance costs as well. The lifecycle cost per ton of carbon is Rs.193 and per ha is Rs. 275 at a discount rate of 6%. The Net Present Value (NPV) of benefits, of interest to policy makers and the local community, is positive at Rs. 3/t C and Rs. 1,042/ha, at 6% discount rate.

Cost:benefit analysis of the baseline and project scenarios was performed to estimate the NPV of benefits (Table 9). The best alternative to agroforestry and the dominant pre-plantation crop is chilli, which is economically viable and most preferred in this region. The PV of costs and benefits and the benefit–cost ratio were estimated. The annual cost/ha for 2006–2035 worked out to Rs. 13,365 under the baseline, compared to Rs. 4,855 for Eucalyptus clones in the project case. The benefits accrued to the communities from the fourth year. The benefit–cost ratio

Table 9 Costs and benefits under baseline and project scenarios for the period 2006–2035

	Baseline scenario[a]	Project scenario
PV of cost (Rs./ha)	13,364	4,855
PV of benefit (Rs./ha)	19,041	10,566
NPV of benefit (Rs./ha/year)	5,677	8,011
Benefit–cost ratio	1.42	2.18

[a] The best alternative to plantations—chilli crop—has been considered for baseline scenario. Rs. 45 = US $1 roughly

under baseline is 1.42, while under the project scenario is 2.18. Thus, there is a large financial incentive for the communities to take up afforestation. Though the project scenario is financially attractive compared to the baseline scenario, the upfront cost of Rs 47,664/ha is an investment barrier especially to small and marginal farmers.

9 Discussion

Agroforestry systems or projects provide significant sustainable development benefits such as food security and secure land tenure in developing countries, increasing farm income, restoring and maintaining aboveground and belowground biodiversity, maintaining watershed hydrology, and soil conservation. Agroforestry also mitigates the demand for wood and reduces pressure on natural forests (Pandey 2002). India is estimated to have between 14,224 million (Ravindranath and Hall 1995) and 24,602 million (Prasad et al. 2000) trees outside forests, spread over an equivalent area of 17 million ha (GOI 1999) supplying 49% of the 201 million tons of fuelwood and 48% of the 64 million cum of timber consumed annually (Rai and Chakrabarti 2001). Forestry mitigation projects provide an opportunity to promote agroforestry in India.

The significance of agroforestry with regards to carbon sequestration is widely recognized, but there is still a paucity of quantitative data. This paper discusses the carbon storage potential of an industry-promoted agroforestry system.

Several studies have shown that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create carbon sinks (Winjum et al. 1993; Dixon 1995). The amount of carbon sequestered largely depends on the agroforestry system, structure and function, which are determined by environmental and socio-economic factors, tree species and the way the system is managed (Albrecht et al. 2003). Use of the Eucalyptus clones promoted by ITC Bhadrachalam in Khammam district, Andhra Pradesh, ha been successfully implemented as a major research and development project to improve productivity and profitability of plantations and make farm forestry an attractive land use option. The major emphasis has been on genetic improvement of planting stock and improvement in the package of practices used by growers (Kulkarni 2002).

9.1 Carbon inventory technique

9.1.1 Aboveground biomass

Variation in productivity can be significant even with regard to clonal varieties. Apart from genetic quality of planting stock, site quality, adaptability of clones to specific sites, implementation of improved package of practices and effective protection of plantations from damage by pests and cattle are important factors that determine the overall productivity of plantations. The clones given farmers are matched to site quality including soil profile and analysis of soil samples to ensure maximum productivity. For pulp production, a uniform spacing of 3×2 m is adopted. Thus, the aboveground biomass in the region by clone can be obtained from the Clonal Multiplication Area or gene bank maintained by the company. In addition, CAI of plantations for various clone types is computed from experimental plots.

The productivities can be verified at the farm gate, where farmers harvest the plantations after 4 years. MAI or CAI values for Bhadrachalam clones in farmlands can be estimated with minimum uncertainty. The survival percentage of a majority of plantations is reported to be more than 95% (Kulkarni and Lal 1995). Thus the annual increments in aboveground biomass can be estimated without periodic field monitoring.

9.1.2 Belowground biomass

Biomass of structural roots of trees increases monotonically with that of aboveground biomass. According to the Good Practice Guidance of IPCC, a default conversion factor of 0.26 of aboveground biomass can be used to calculate the belowground biomass (IPCC 2003). A comprehensive literature review by Cairns et al. (1997) including more than 160 studies covering native tropical, temperate, and boreal forests, reported aboveground an average belowground to aboveground dry biomass ratio of 0.26, with a range of 0.18 (lower 25% quartile) to 0.30 (upper 75% quartile). The BGB of 1- to 5-year plantations ranged from 0.36 to 0.22 with an average of 0.26 (Table 6), confirming the global literature average.

There is dearth of information concerning root dynamics of short-rotation systems. According to Cannell and Smith (1980), the structural root biomass production is about 2–3 t/ha/year for aboveground biomass productivity of 10–12 t/ha/year in a short-rotation plantation thus constituting 20–25% of the AGB. Further studies are required to understand the root dynamics in short-rotation plantations.

9.1.3 Soil organic carbon

Following afforestation, changes in soil organic carbon occur in quality, quantity and spatial distribution. Abiotic factors such as site preparation, previous land use, climate, soil texture, site management and harvesting affect the extent of SOC after afforestation (Paul et al. 2002). The SOC change after afforestation for various age classes was determined by sampling an adjacent area with similar pre-project conditions. There was a loss of SOC during the initial 4 years after afforestation, consistent with observations on sites repeatedly measured over time, due to little input of carbon from aboveground biomass due to low litterfall (Wilde 1964). These studies also showed an initial loss of SOC followed by a gradual increase. In long-term studies, SOC is generally found to accumulate following afforestation, when annual inputs of carbon through primary production exceeded the amount lost by decomposition.

The plantations receive fertilizers annually through the rotations to increase biomass productivity. The efficacy of fertilizer application in SOC sequestration is debatable. There are hidden carbon costs to the fertilizer input (Schlesinger 2000). Nitrogenous fertilizers have hidden costs of 0.86 kg C/kg N (IPCC 1996). This ratio has been used to calculate the C emissions in the project area. Similar to fertilizers, irrigation enhances aboveground and belowground biomass, which increases the return of BGB in soil and improve SOC concentration. One practice followed by farmers is burning of non-pulpable biomass on-site after harvest, which emits numerous gases immediately but also leaves charcoal as residual material that may constitute up to 35% of the total SOC pool (Skjemstad et al. 2000). Charcoal is extremely resistant to combustion; it is not cycled like most organic matter and has a mean residence time of 10,000 years. Thus, on-site burning increases SOC in the soil by a large fraction, during the fifth year.

The resulting estimations for the project site indicate a sharp initial loss of soil C in the plantation, with inputs finally exceeding outputs to soil C beginning at year 5. Based on literature, a new equilibrium state is usually reached by 10 years (Nigeria), 30 years (Congo) or 40–60 years in (Massachusetts). In the present case study, the accumulation of SOC is assumed until the eighth year, which is a conservative estimate.

Thus, in a complex system with multiple practices such as tillage, fertilizer application, irrigation, the annual impact on SOC is rapid. Monitoring of SOC may need to be frequent (2 years once) in C projects. Continuous observations of soil C under short-rotation plantations and under adjacent land uses over entire rotations are required. The most accurate method to measure SOC change is to repeatedly sample the site over time and analyze consistently, but the tradeoff between monitoring costs and soil C benefits needs to be evaluated.

9.2 Additionality

The major reasoning used to address additionality is to estimate what changes in land use of the area would have occurred if the sequestration project had not taken place. One significant consideration in this case is the baseline rate of plantation establishment planned and implemented by ITC in the regional generally and project area specifically. If lands can be identified and analyses presented demonstrating they are highly unlikely to be planted with ITC support or otherwise in the baseline case, then additionality is likely to be successfully argued (as long as other additionality tests required by a given GHG mitigation program are also met, as discussed).

9.3 Baseline development

There are two approaches to baseline development. Project-specific baselines draw upon site-specific information, as demonstrated in this study. Benchmark or Regional baselines evaluate land use and management trends across an entire region, which could be a district or a block within a district with similar geographic conditions. A benchmark value of C uptake or emissions for a given land use and site quality can then be set, and potential projects assessed against it. This regional approach could be practical as it could lower transaction costs and avoid the complexity of determining baselines for individual projects. It also allows for quick, low-cost replication of the first project and also helps provide objectivity and transparency in estimating the baseline and GHG additionality. A regional approach also helps in identifying potential project sites or activities, since regional baseline activity rates and locations are known and mapped. For example, ITC could target lands according to land tenure (i.e., low income farmers compared to richer farmers) and locations or patterns for adoption of clonal planting that are unlikely to be planted under the projected baseline—addressing the additionality concern. However, this study did not assess the potential of using a regional approach (which is specifically addressed in a similar study in Kolar district, Karnataka, in southwest India (Sudha et al., this issue).

9.4 Leakage

Leakage was not an issue in this case study, as carbon stock under the baseline scenario is static and the project produces new biomass plantations that help divert farmer pressure on natural forests. But the domain necessary for monitoring project leakage, positive spillover and market transformation may be larger. Not all secondary impacts can be predicted (Vine et al. 2001). For example, the project activity may lead to encroachment on forest areas for agriculture. Thus widening the analytic boundary may help in capturing secondary leakage if it occurs. For small projects, leakage impacts may be small and the focus can be only on carbon stocks within the project, which will cut down monitoring costs.

9.5 Monitoring of carbon stock change

The measurement of carbon sequestration in a project necessitates monitoring using specialized methods largely based upon standard forestry approaches to biomass measurement and analysis, and applying commonly accepted principles of forest inventory, soil science and ecological surveys. The specific methods and procedures should be tailored to the circumstances of a given project (Vine et al. 2001). Monitoring can be based on modeling, remote sensing, and field/site measurements, including biomass surveys, research studies, surveys, the monitoring of wood production and end products, forest inventories, and destructive sampling (MacDicken 1998). One of the most dynamic carbon pools is the SOC. The SOC changes due to land conversion from agriculture to plantation generally results in a build-up of soil C, although the process may be slow, often requiring from 10 to as many as 200 years (Post and Kwon 2000). A more widely reported pattern is an initial decrease in soil C immediately after forest establishment followed by a long-term increase. It is therefore essential to measure the soil organic carbon pool periodically, especially in the project area but potentially also in control areas.

The AGB change is well researched, so determination of the CAI may not be required in the project area, since AGB can be determined from calculated biomass expansion factors. The pulpable wood that has sequestered carbon at the end of rotation period can be determined at the farm gate. The default conversion factor can be used to determine BGB from AGB values, although importantly further research is required to estimate the BGB ratio to AGB in harvest regimes beyond the first rotation period.

9.5.1 Cost-effectiveness

Cost-effectiveness analysis of the project activity was done based on the investment required for establishment of plantations and returns that accrue from them. Monitoring costs have been included every 4 years. As an economic activity, the project is viable. Further, the calculation of cost-effectiveness inclusive of transaction costs and the carbon price allows evaluation of financial parameters in terms of the usual metric of costs and benefits per t C abated.

9.6 Socio-economic impacts

Agroforestry systems offer significant benefits as a land use at the global, regional, watershed, and farm level because they can provide synergy between increased food production, poverty alleviation and environmental conservation. The benefits of carbon sequestration and trading may reach small and marginal farmers directly through agroforestry, and project activities may increase farm incomes and employment compared to alternative crops. Even in drought period, the farmers would be able to get revenue from the project activity compared to annual agricultural crops.

9.7 Environmental impacts

Some of the adverse effects of climate change are likely to occur in developing countries, where populations are most vulnerable and least likely to adapt to climate change. Forestry mitigation projects potentially can act not only as carbon sinks but also aid in the fulfilling sustainable development goals of the country, including increasing biodiversity. Monocultural Bhadrachalam clone plantations do not enhance biodiversity. But the baseline scenario also has negligible trees, so there is no gain or loss of biodiversity due to the project. The project would improve soil organic carbon and fertility of the soil.

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Appendix

Table 10 Unit cost per hectare for raising and maintenance of a 5-year-old Eucalyptus clonal plantation

Operation	Year				Total
	1	2	3	4	
Ploughing	2,400	2,520	2,646	2,778	10,344
Alignment/staking	150				150
Digging of pits and planting	2,499				2,499
Weeding/cleaning/soil working	1,666	1,749			3,415
Cost of fertilizers/geen manure	2,250	2,363	2,481	2,605	9,699
Cost of anti-termite treatment	1,600				1,600
Provision for fencing/maintenance	2,000	200	200	200	2,600
Contingencies	628	342	266	279	1,515
Cost of plants	14,000				14,000
Insurance premium	340	430	499	573	1,842
Total cost per ha	27,533	7,604	6,092	6,435	47,664

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