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Carbon Sequestration in Multipurpose Agroforesty Plantations by using Monoculture Agroforesty Models

Agriculture

KEYWORDS : Carbon content,carbon storage ,yied class

R. Shankar	Department of Agronomy, College of Agriculture, Acharya N.G Ranga Agricultural University,Rajendranagar, Hyderabad, A.P, India
Ch. Chandra Sekhar	Department of Soil Science and Agricultural Chemistry, College of Agriculture, Acharya N.G Ranga Agricultural University,Rajendranagar, Hyderabad, A.P, India
B. Joseph	Department of Farm Forestry, College of Agriculture, Acharya N.G Ranga Agricultural University,Rajendranagar, Hyderabad, A.P, India
K.B. Sunitha Devi	Department of Agronomy, College of Agriculture, Acharya N.G Ranga Agricultural University,Rajendranagar, Hyderabad, A.P, India
M.A. Aarif Khan	Department of Soil Science and Agricultural Chemistry, College of Agriculture, Acharya N.G Ranga Agricultural University,Rajendranagar, Hyderabad, A.P, India

ABSTRACT

A carbon-flow model for managed agroforesty plantations was used to estimate carbon storage in Acharyear N G Ranga university campus plantations differing in Yield Class(growth rate) and species characteristics. Time averaged, total carbon storage was generally recorded 19,469 kg ha-1 year-1 in trees, 2031 kg ha-1 year -1 in soil organic matter and 3,48,424 kg ha-1 year-1 in wood products. The average rate of carbon storage during early stages in most of the plantations was in 1209 kg C ha-1 year-1. A sensitivity study analysis revaled that average increase in total carbon storage in the tree systems is highest in two tree species viz., Azadirachta indica (6372.0 kg C ha-1 year-1) and Dalbergia sissooo (1415.11 kg C ha-1 year-1). The increase in carbon storage rate was 6-24 m3 ha-1 year-1 and increase in total carbon storage was in the range of 2.5 to 4.6 Mg C ha-1 year-1. If the main objective is to store carbon rapidly in the short term and achieve high carbon storage in the long term, Eucalyptus spp plantations planted in blocks was the best (spacing, year rotations) option. If the objective is to achieve high carbon storage in the medium term without regard to the initial rate of storage, then the plantations of any Dalbergia spp with above 20 years age is suffice. In long term grown broad leaved plantations of Tectona grandis and Azadirachta indica as much carbon stored as the other plantations was observed.

Introduction

Increased greenhouse gases concentration in atmosphere concerned the research works and concentrated attempts were made to measure the net release of CO_2 to the atmosphere resulting from deforestation (Alves et al., 1997; Baes et al., 1977; Brown et al.,1997; 2004, David 1993; Negi et al., 1988; Ramachandran et al., 2007). Similar works were carried out by scientists to calibrate the carbon sequestration rate by different tree species (Dilling et al., 2006; Hairiah, 2006; Chavan and Rasal, 2010). Different workers have variously concentrated on the amount of carbon stored in the existed trees (Chavan B.L. and Rasal G.B., 2009, 2010, 2011; Gurmit singh, 2009; Jana et al., 2009; Kenzo, 2009; Schumacher, 2003), the wood products (Negi et al., 1988; Wilde et al., 1964) and the tree-soil ecosystem dynamics (Cropper and Ewel 1983). Few studies have compiled the micro-level tree-soil-product system and traced the flow of carbon from trees to soil products in a dynamic system, as outlined in the model proposed by Dewar (1991). In this paper, the Dewar (1991) model is used to explore the options for storing carbon by establishing new plantations with different growth rates and by different species. The analysis is restricted to ANGRAU campus in AP, but the findings apply more widely. The study was in part, a sensitivity analysis of the variables in the carbon flow model and in part, a comparison of plantations types using best-guess parameters values. The model describes the accumulation and dynamics of carbon in even aged and single-species plantations. Carbon sequestration in each plantation is represented by growth and increase in biomass of tree species (includes its woody and non-woody parts with different wood characters). As the trees continuously take considerable amount of CO_2 and convert it into biomass by photosynthesis process, the rate of carbon intake is also proportionally increased. The model doesn't take ground vegetation into account and assumes that the pattern of tree growth is the same in successive rotations with no major catastrophes such as wind throw or pest outbreaks. Also, it is assumed that negligible amounts of carbon are permanently lost from the system into groundwater or to recalcitrant soil organic matter.

Material and Methods

Carbon storage was calculated in seven contrasting types of forest and wood land plantations with varying growth rates and other characteristics typical of Andhra Pradesh conditions. The systems chosen were (1) The Albizia lebbeck based agri-silvi system was initiated during the year 1993 on red sandy clay loam soil and planted at a spacing of 8x4 m in campus afforestation programme (Yield Class4-14 m^{-3} ha^{-1} $year^{-1}$), (2) Acacia nilotica based silvi-pasture system chosen for the study was initiated during the year 1993 on an Alfisol with the spacing of 4x4m in the campus afforestation programme (Yield Class9-27 m^{-3} ha^{-1} $year^{-1}$), (3) Eucalyptus tereticornis block trees were planted during the year 1989 at 2x2 m spacing on red sandy loam soils (Yield Class 35-135 m^{-3} ha^{-1} $year^{-1}$), (4) Azadirachta indica block trees were planted at 4x4 m spacing during the 1989 on red sandy soils (Yield Class 35-135 m^{-3} ha^{-1} $year^{-1}$), (5) Tectona grandis block trees were planted at 3x3 m spacing during the year 1989 on red loam soils (yield class14-48 m^{-3} ha^{-1} $year^{-1}$), (6) Dalbergia sissoo block trees were planted at 3x3 m spacing during 1989 on ready loam soils (Yield Class16-57 m^{-3} ha^{-1} $year^{-1}$) and (7) Pongamia pinnata block was planted at 4x4 m spacing during 1995 on red sandy soils (Yield Class 8-27 m^{-3} ha^{-1} $year^{-1}$).

Calculation of carbon storage

The estimation of carbon sequestration and storage in the existed trees species was done by felling tree material (destructive method). Tree samples (leaf, twig and wood along with bark) collected from different species under seven land use systems (except fallow land) selected for the study were dried in an electric oven at 60oC, powdered and used for estimation of carbon. Carbon status was determined in different parts such as leaf, twig and wood along with bark. The carbon content was determined by Perkin Elmer 2400 CHN Elemental Analyzer, except that numerical estimates based on the yield classes were used to calculate carbon in the woody biomass of living trees and the non-woody biomass (foliage) was explicitly represented.

The sequestration rate of carbon increases with age of trees at earlier ages and sticks to a limit at their maximum ages. Carbon storage of tree block is affected by its natural mortality and pest out brake damages, but in this experiment these conditions were taken as neutral assumption. The net amount of carbon in living trees for each year was estimated numerically by dividing total amount of carbon of tree by its age. The tree biomass converted to carbon mass (Mg) by:

Carbon mass = volume × f_c

f_c is the mean fraction of carbon in dry biomass.

The carbon sequestration capacity of tree species is estimated by destructive method.

CO_2 is composed of one molecule of Carbon and 2 molecules of Oxygen.

The atomic weight of Carbon is 12.0

The atomic weight of Oxygen is 15.9

The weight of CO2 is C + 2 × O = 43.9

The ratio of CO2 to C is 43.9/12.0 = 3.6

Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.6

Results and Discussion:
The predicted equilibrium carbon storage in different types of plantations, using the standard parameter values in tables to compare between different aged and different species of plantations, plantations of different yield classes and between species with contrasting average growth and product. In order to knowing how much and where (in trees, products, litter and soil) the carbon is stored, it is important to know how rapidly storage occurs. However, for all plantations, the time taken to reach 95 % of total equilibrium carbon storage was over 80 years, because of the limitation imposed by the slow build up of soil organic matter. A more useful parameter is the initial rate of increase in total carbon storage. These values are given in Table 5.

An increase in Yield Class means an increase in the rate of carbon accumulation in the trees (despite a decrease in stem wood basic density), a shorter rotation and larger and more frequent transfers of carbon. Consequently, whatever the species, an increase in Yield Class increases carbon storage in all carbon pools. For an increase in Yield Class from 16.52 to 57.35 m^3 ha^{-1} y^{-1} was predicted to increase total carbon storage by about 293 kg t^{-1} highest in Dalbergia sissoo tress. The maximum biomass accumulation in Dalbergia sissoo (533.91 kg $tree^{-1}$) might be due to its high energy conversion efficiency, photosynthetic rate (Srivastava and Ram 2009) and higher number of nodules formation in the roots as compared to other species (Kimothi et al., 1983). Similar results were obtained by Kok et al., (1973) and Kok et al., (1976). The wood of Dalbergia sissoo is also heavy as compared to other species (Pearson and Brown, 1932). As the Yield Class increased, the trees and wood products contained a larger fraction of the total carbon and less percentage of per year carbon storage and CO_2 sequestration capacity (Fig. 4). The average increase in total carbon storage per unit increase in Yield Class (1 m^3 ha^{-1} y^{-1}) was 88 kg t^{-1} $year^{-1}$ in Eucalyptus and Teak stands . The rate of early aged accumulation of carbon over the old aged stands is more than thrice with increase in all Yield Class irrespective of tree species (Fig. 4). There was a 2-3 fold variation in the predicted total carbon storage in different plantation types, with different parameters. The largest carbon storage in Dalbergia sissoo (267 kg $tree^{-1}$) exceded the predicted total storage in Yield Class 16-57 m-3 ha^{-1} y^{-1} and among other species that were assigned Eucalyptus Yield Class 35-135 m^{-3} ha^{-1} y^{-1} generally had the fastest initial rate of carbon storage, but not necessarily the greatest total storage at equilibrium (Table. 5). Thus, the time-averaged carbon storage in Dalbergia sissoo plantations at Yield Class 16-57 m^{-3} ha^{-1} y^{-1} was greater than that of Eucalyptus plantations at Yield Class 35-135 m^{-3} ha^{-1} y^{-1} (Table.5), because Dalbergia sissoo plantations have high photosynthetic rate, energy conversion efficiency which resulted in utilisation of maximum CO_2 for production of biosynthates that exist for longer periods with a large biomass. Species differences in CO_2 sequestration efficiency lengths (product lifetimes) can also counteract the expected effects of differences in Yield Class on total carbon storage. The time-averaged carbon storage in trees was also large (66 Mg C ha^{-1}) and these large quantities of carbon were transferred at the end of each rotation to the product and litter/soil carbon pools. Total equilibrium carbon storage of Dalbergia sissoo (871 kg tree-1) was also found to be higher than the other tree species. Compared with other plantation types, relatively high carbon accumulated in the Dalbergia trees during each rotation and little was transferred to products. Acacia nilotica (846 kg $tree^{-1}$) plantations were found to be approximately as effective as typical Dalbergia plantations in storing carbon (Table.2). However, Acacia nilotica had a faster initial rate of storage than Dalbergia plantations (4.6 Mg C ha^{-1} $year^{-1}$). There were relatively small differences in carbon storage among the seven tree species plantations examined (Fig.1). In all cases, over 80% of the total carbon was stored in stem and leafs, suggesting that there may be little merit in refining the estimates of biomass accumulation. There seems little difference in CO_2 sequestration among Tectona grandis (832.77 kg $tree^{-1}$), Pongamia pinnata (830.86 kg $tree^{-1}$) and Acacia nilotica (822.31 kg $tree^{-1}$) and the lowest was recorded in Albizia lebbeck (791.43 kg $tree^{-1}$) (Table.5) This might due to low energy conversion efficiency (ECE), efficiency of utilization of solar energy at cellular level of these tree species resulting in low CO_2 sequestration capacity and low carbon storage compared to Dalbergia spp Yield Classes and wood products. The time-averaged carbon storage in these trees was similar to that of Dalbergia at Yield Class 16-57 m^3 ha^{-1} $year^{-1}$ which might be due to the large branch wood fraction.

Table 1: Carbon content (kg p^{-1}) in different aged agroforestry tree species

Plant species	9-15 years	15-25 years	25-30 years	30-35 years	35 - above	Mean
Acacia nilotica	196	249	272	288	294	260
Dalbergia sissooo	232	244	280	288	291	267
Eucalyptus tereticornis	243	248	254	253	285	256
Albizia lebbeck	203	222	240	258	269	238
Pongamia pinnata	196	241	227	238	264	233
Tectona grandis	196	245	252	255	265	243
Azadirachta indica	197	242	255	266	264	245
SEm±	5.29					
CD (0.05%)	15.54					
CV (%)	4.75					

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Table 2: CO_2 sequestration (kg p^{-1}) in different aged agroforestry tree species

Plant species	9-15 years	15-25 years	25-30 years	30-35 years	35 - above	Mean
Acacia nilotica	640	813	886	938	958	847
Dalbergia sissooo	758	797	913	939	948	871
Eucalyptus tereticornis	793	808	828	824	928	836
Albizia lebbeck	661	725	782	842	878	777
Pongamia pinnata	640	786	740	776	860	761
Tectona grandis	638	800	821	832	866	791
Azadirachta indica	641	791	833	869	861	799
SEm±	17.28					
CD (0.05%)	50.75					
CV (%)	4.76					

Table 3: Amount of biomass accumulated (kg p^{-1}) in different aged agroforestry plant species

Plant species	9-15 years	15-25 years	25-30 years	30-35 years	35 - above	Mean
Acacia nilotica	393	498	543	575	588	519
Dalbergia sissooo	465	488	560	576	581	534
Eucalyptus tereticornis	486	495	508	505	569	513
Albizia lebbeck	405	445	479	516	539	477
Pongamia pinnata	392	482	454	476	527	466
Tectona grandis	391	490	503	510	531	485
Azadirachta indica	393	485	511	533	528	490
SEm±	10.58					
CD (0.05%)	31.07					
CV (%)	4.75					

Table 4: Yield Classm-3 ha^{-1} y^{-1} in different aged agroforestry tree species

Plant species	9-15 years	15-25 years	25-30 years	30-35 years	35 - above	Mean
Acacia nilotica	27.3	15.6	13.6	10.3	9.2	15.2
Dalbergia sissooo	57.4	27.1	24.9	18.3	16.2	28.8
Eucalyptus tereticornis	135.1	61.9	50.8	36.1	35.6	63.9
Albizia lebbeck	14.1	7.0	6.0	4.6	4.2	7.2
Pongamia pinnata	27.3	15.1	11.4	8.5	8.2	14.1
Tectona grandis	48.3	27.2	22.4	16.2	14.8	25.8
Azadirachta indica	27.3	15.2	12.8	9.5	8.3	14.6
SEm±	5.71					
CD (0.05%)	16.78					
CV (%)	52.75					

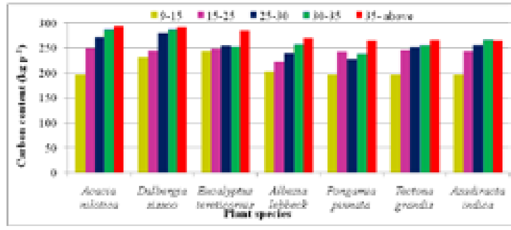


Fig. 1: Carbon content (kg p^{-1}) in different aged agroforestry tree species

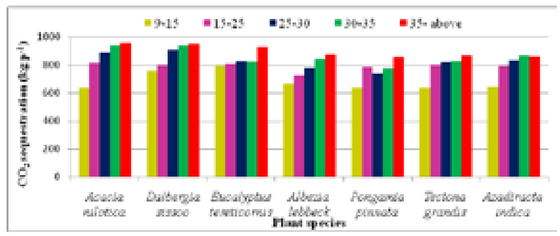


Fig. 2: CO_2 sequestration (kg p^{-1}) in different aged agroforestry tree species

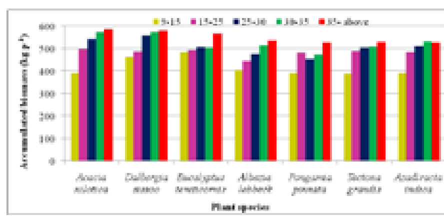


Fig.3: Amount of biomass accumulated (kg p^{-1}) in different aged agroforestry tree species

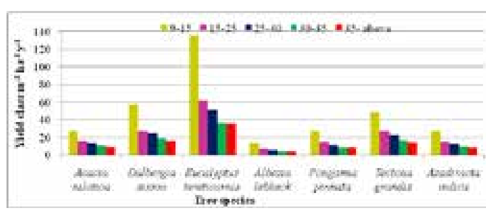
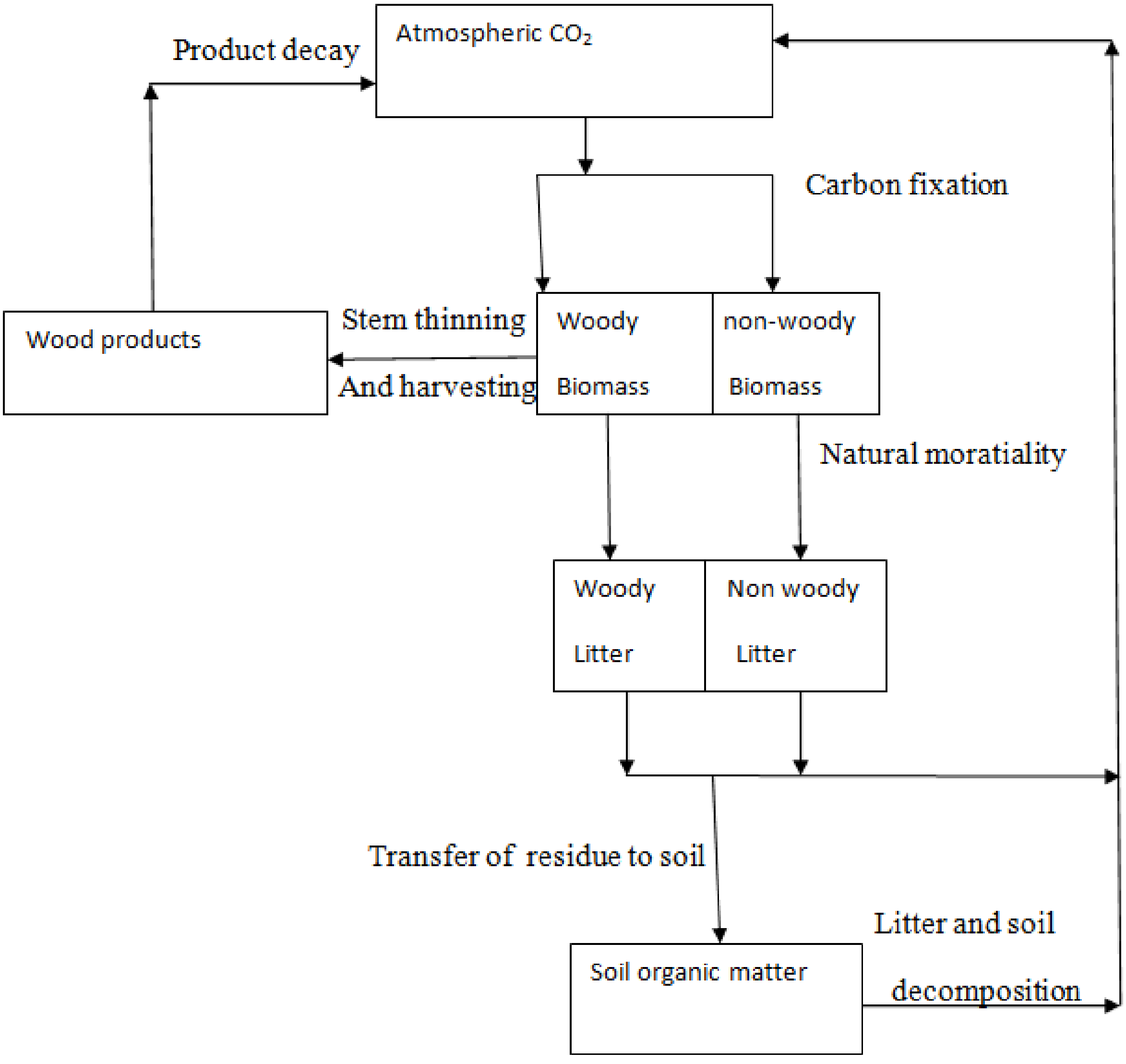


Fig.4: Yield Classm^{-3} ha^{-1} y^{-1} in different aged agroforestry tree species

Table 5: Summary of the details of study of different aged Agroforestry tree species

Plant species	Age of plant species in years	Amount of biomass accumulated (kg p^{-1})	Carbon content (kg p^{-1})	Yield class m^3 ha^{-1} y^{-1}	CO_2 sequestration (kg tree^{-1})	Location
Acacia nilotica	9-15	392.70	196.35	27.27	640.4	Student farm
Dalbergia sissooo	9-15	464.56	232.28	57.35	757.6	Student farm
Eucalyptus tereticornis	9-15	486.46	243.23	135.13	793.3	Student farm
Albezia lebbeck	9-15	405.00	202.5	14.06	660.5	Student farm

Plant species	Age of plant species in years	Amount of biomass accumulated (kg p^{-1})	Carbon content (kg p^{-1})	Yield class m^3 ha^{-1} y^{-1}	CO_2 sequestration (kg $tree^{-1}$)	Location
Pongamia pinnata	9-15	392.44	196.22	27.25	640.0	Student farm
Tectona grandis	9-15	391.06	195.53	48.28	637.7	Student farm
Azadirachta indica	9-15	393.20	196.60	27.31	641.2	Student farm
Acacia nilotica	15-25	498.36	249.18	15.57	812.7	College farm
Dalbergia sissoo block	15-25	488.40	244.20	27.13	796.5	College farm
Eucalyptus tereticornis	15-25	495.30	247.65	61.91	807.7	College farm
Albezia lebbeck	15-25	444.68	222.34	6.95	725.2	College farm
Pongamia pinnata	15-25	482.02	241.01	15.06	786.1	College farm
Tectona grandis	15-25	490.34	245.17	27.24	799.6	College farm
Azadirachta indica	15-25	484.92	242.46	15.15	790.8	College farm
Acacia nilotica	25-30	543.34	271.67	13.58	886.1	Agriculture Research Institute
Dalbergia sissoo	25-30	559.58	279.79	24.87	912.6	Agriculture Research Institute
Eucalyptus tereticornis	25-30	507.86	253.93	50.79	828.2	Agriculture Research Institute
Albezia lebbeck	25-30	479.22	239.61	5.99	781.5	Agriculture Research Institute
Pongamia pinnata	25-30	454.02	227.01	11.35	740.4	Agriculture Research Institute
Tectona grandis	25-30	503.36	251.68	22.37	820.9	Agriculture Research Institute
Azadirachta indica	25-30	510.78	255.39	12.77	833.0	Agriculture Research Institute
Acacia nilotica	30-35	575.10	287.55	10.27	937.9	Horticultural college
Dalbergia sissoo	30-35	575.58	287.79	18.27	938.7	Horticultural college
Eucalyptus tereticornis	30-35	505.14	252.57	36.08	823.8	Horticultural college
Albezia lebbeck	30-35	516.08	258.04	4.61	841.6	Horticultural college
Pongamia pinnata	30-35	475.80	237.90	8.50	775.9	Horticultural college
Tectona grandis	30-35	509.88	254.94	16.19	831.5	Horticultural college
Azadirachta indica	30-35	532.88	266.44	9.52	869.0	Horticultural college
Acacia nilotica	35above	587.56	293.78	9.18	958.2	Veterinary college
Dalbergia sissoo	35above	581.42	290.71	16.15	948.2	Veterinary college
Eucalyptus tereticornis	35above	569.3	284.65	35.58	928.4	Veterinary college
Albezia lebbeck	35above	538.52	269.26	4.21	878.2	Veterinary college
Pongamia pinnata	35above	527.44	263.72	8.24	860.1	Veterinary college
Tectona grandis	35above	530.82	265.41	14.75	865.7	Veterinary college
Azadirachta indica	35above	528.14	264.07	8.25	861.3	Veterinary college



Dewar model 1991;pool and carbon fluxes represented in model

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