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Carbon sequestration potential of different land use systems in semi-arid regions of Karnataka

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Abstract

The study was conducted in different land use systems *viz*., tree plantations (*Tectona grandis, Terminalia bellirica, Swietenia macrophylla, Artocarpus hirsutus*), natural forest, horticulture (*Mangifera indica*) and agroforestry (*Melia dubia*) at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka. The CO_2 sequestered in tree biomass was recorded highest under *A. hirsutus* (3182.03 Mg/ ha) followed by *T. bellirica* (1519.66 Mg/ ha), whereas the lowest CO_2 was sequestered under horticulture system (127.65 Mg /ha) followed by agroforestry (196.47 Mg/ha). Highest SOC (Mg/ha) was recorded under natural forest (25.59 Mg/ha) followed by *S. macrophylla* (17.44 Mg/ha) and it is lowest under horticulture (10.59 Mg/ha). The litter carbon was highest under *A. hirsutus* (3.87 Mg/ha/year) and lowest under *T. grandis* (1.16 Mg/ha/year). The highest CO_2 was sequestered under *A. hirsutus* (3321.44 Mg ha^{-1}) followed by *T. bellirica* (160.80 Mg ha^{-1}) and least under horticulture system (469.36 Mg ha^{-1}). The variation in carbon sequestration potential among the land use systems was mainly due to species, spacing and age of the trees.

Keywords: tree biomass, litter carbon, soil organic carbon, plantations

Introduction

Climate is changing rapidly and its adverse effect has been experienced in different parts of the world. Increase in the concentration of greenhouse gases (GHGs) in the atmosphere released primarily through the burning of fossil fuels, deforestation and agricultural and industrial processes is generally accepted to be the primary contributor to global warming (Pfaff *et al*., 2000) [16]. Many recent studies suggests that the planet Earth is getting warmer and have brought about lot of negative changes in the global climate. Rising global temperature, erratic rainfall, reoccurring droughts and floods have severely affected the well-being of mankind. Tree based land use systems has emerged as the low-cost methods to sequester carbon in the context of global climate change. Tree incorporation on crop and pasture lands results in greater net above-ground as well as below-ground carbon sequestration (Palm *et al*. 2004; Haile *et al*. 2008) [14, 6]. In semi-arid regions of Karnataka farmers take up different tree-based land use systems *viz.*, tree plantations (monoculture), agroforestry systems and horticulture. All these tree-based systems produce large amounts of biomass and sequester carbon from the atmosphere. There is a need to understand the carbon sequestration potential of these land use system. Therefore, the present study was undertaken to assess the carbon sequestration potential of standing trees in the major tree-based systems of the semi-arid regions of Karnataka.

Materials and Methods

The study was conducted in different land use systems at University of Agricultural Sciences, GKVK, Bengaluru, Karnataka. It is located in the Northern part of Bengaluru between Latitude: 13^0 05' North and Longitude: 77^0 34' East and Altitude: 924m (above mean sea level). The land use systems selected for study were tree plantations (*Tectona grandis*, *Terminalia bellirica*, *Swietenia macrophylla*, *Artocarpus hirsutus*), natural forest, horticulture (*Mangifera indica*) and agroforestry (*Melia dubia*). Tree plantations were established in the year 1986, horticulture system in the year 1977 and agroforestry system in the year 2010. The tree were planted in different spacing: tree plantations at 2m x 2m, horticulture at 10 m x 10 m and agroforestry 8m x 5m.

The height of all the trees in each land use system was measured using a Ravi altimeter. Girth at breast height (GBH) was measured at 1.37 m from the ground level over the bark with the help of measuring tape. Non-destructive method of biomass estimation was carried out using volume (tree height, DBH) and wood density (Brown, 1997) [3].

The following formula was used for calculating the standing volume of trees

Volume (m^3) = π $(D/2)^2 \times H$

where $\pi = 3.14$, D is the diameter at breast height (DBH; m), i.e. one-third of GBH, and H is the height of the tree (m).

Above-ground biomass (AGB; kg tree^{-1})

AGB= Volume (m^3) × wood density (kg m^{-3}).

Below-ground biomass (BGB)

BGB of the tree includes live root biomass, excluding fine roots and was calculated using 0.26 factor of root : shoot ratio (Ravindranath and Ostwald, 2008) [19].

BGB (kg tree^{-1}) = AGB (kg tree^{-1}) × 0.26.

Total biomass (TB)

Sum of AGB and BGB gives total biomass (TB) of the tree

TB (kg tree^{-1}) = AGB (kg tree^{-1}) + BGB (kg tree^{-1})

Carbon estimation

Generally, for any plant species 45-50% of its biomass is considered as carbon (Pearson *et al*., 2005[]15) i.e.,

Carbon Storage = Biomass x 50%

CO_2 sequestration

The atomic weight of Carbon is considered as 12.00. The atomic weight of Oxygen is considered as 16. The weight of CO_2 is C+2xO=43.999915. The ratio of CO_2 to C is 43.999915/12.00=3.66. Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.66.

Soil organic carbon stock (SOC)

The organic carbon concentration in the soil was converted to total SOC pool as per Kukal *et al*. (2009) [8] as follows:

$$\text{Total SOC pool} = \frac{\%SOC}{100} \text{ x } (\text{Db x } 2000)$$

where, total SOC pool is weight of soil organic carbon (Mg ha^{-1}), SOC is soil organic carbon (%), Db is soil bulk density of 0–20 cm/20-40 cm/ 40-60 cm layer (Mg m^{-3}) and 2000 is the volume of 1 ha furrow slice (0.20 m) (m^3).

Litter carbon stock

The litter traps were only laid out in tree plantations and natural forest. The litter carbon was estimated using CN analyzer. The total leaf litter accumulated per hectare per year was multiplied with the carbon content to arrive at the total litter carbon in a land use system.

Total CO_2 pool and valuation

The tree CO_2, soil $CO_2$and litter CO_2 were pooled together to arrive at total CO_2 pool in a land use system. As per the existing carbon trading mechanism, one CER (Certified Emission Reduction) is equal to one tonne of CO_2. At present market price of one CER is $0.4 (UNFCCC, 2017) [26]. The total CO_2 sequestered is multiplied with CER to arrive at the economic value of CO_2 sequestered.

Results and Discussion

Tree Carbon

The aboveground biomass varied between the land use systems (Table 1 and Fig. 1). The highest aboveground biomass was recorded under horticulture system (553.14 kg/tree) followed by *A. hirsutus* tree plantations (551.55 kg/tree). The lowest was recorded under *T. grandis* (135.51kg/tree) followed by *S. macrophylla* (205.44 kg/tree). The belowground biomass also was highest under horticulture system (143.82 kg/tree) followed by *A. hirsutus* (143.40 kg/ tree). The total biomass was highest under horticulture system (696.96 kg/tree) followed by *A. hirsutus* (694.96 kg/tree). The lowest total biomass was recorded under *T. grandis* (170.74 kg/tree) followed by *S. macrophylla* (258.86 kg/tree). In horticulture system (1276.48 kg/tree) highest CO_2 was sequestered per tree, whereas lowest was recorded under *T. grandis* (312.72 kg/tree). The CO_2 sequestered in tree biomass for a hectare varied among the land use systems mainly due to tree spacing and highest was recorded under *A. hirsutus* (3182.03 Mg/ ha) followed by *T. bellirica* (1519.66 Mg/ ha) (Table 1 and Fig. 2). Whereas the lowest CO_2 was sequestered under horticulture system (127.65 Mg /ha) followed by agroforestry (196.47 Mg/ha).

Table 1: Carbon sequestration under different land use systems

Land use	No. of trees/ha	ABG (kg/tree)	BG (kg/tree)	Total Biomass (kg/tree)	Carbon kg/tree	CO_2 kg/tree	Carbon Mg/ha	CO_2 (Mg/ha)
T. grandis	2500	135.51	35.23	170.74	85.37	312.72	213.43	781.80
T. bellirica	2500	263.41	68.49	331.89	165.95	607.87	414.87	1519.66
S. macrophylla	2500	205.44	53.41	258.86	129.43	474.10	323.57	1185.24
A.hirsutus	2500	551.55	143.40	694.96	347.48	1272.81	868.70	3182.03
Natural forest	460	280.97	73.05	354.03	177.01	648.40	81.43	298.26
Horticulture	100	553.14	143.82	696.96	348.48	1276.48	34.85	127.65
Agroforestry	250	340.54	88.54	429.08	214.54	785.86	53.64	196.47

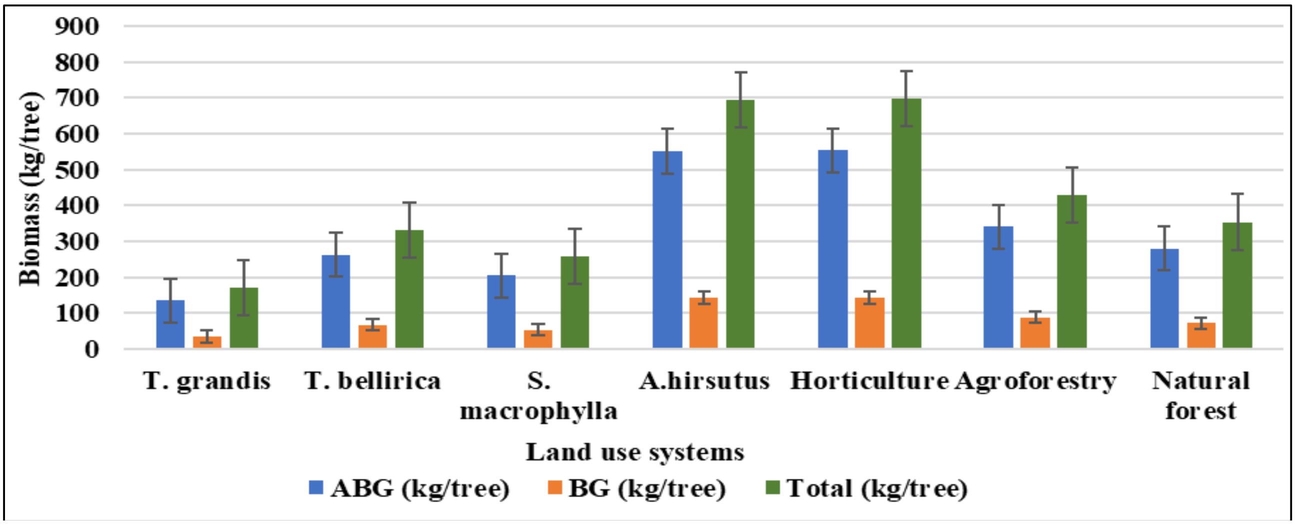

Fig 1: Aboveground biomass (ABG), belowground (BG) biomass and total biomass under different land use systems.

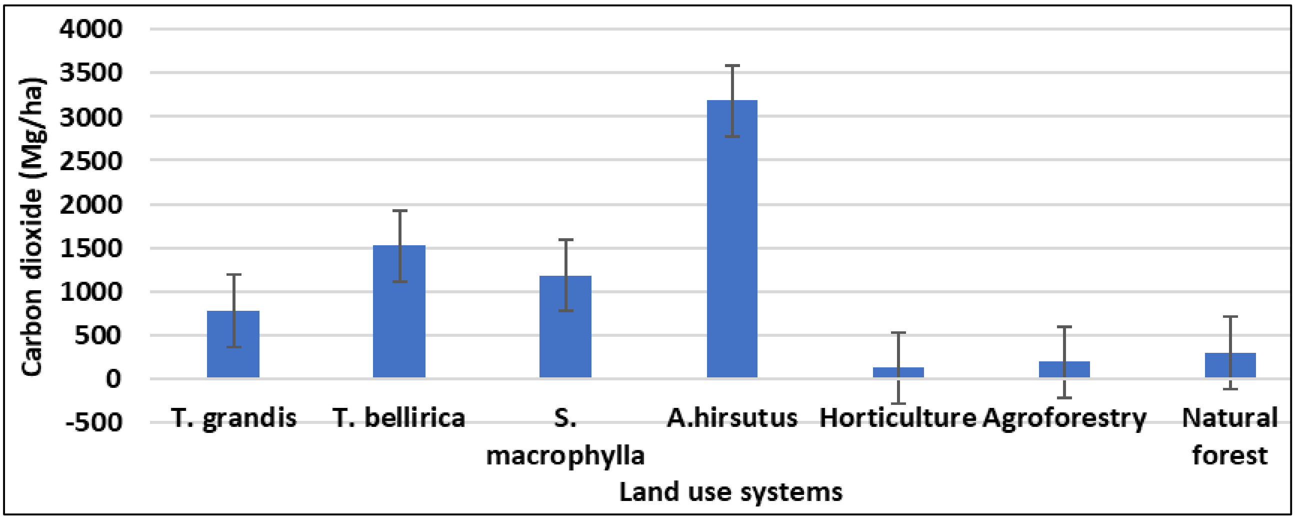

Fig 2: CO_2 sequestration potential in tree biomass under different land use system.

The total carbon sequestered by trees depends on species, age of the tree, planting geometry and growth rates of species. There are many studies to show the effect of each of these factors on carbon sequestration from tree based land use systems. The tree density varied from 100 trees/ha to 2500 trees/ha. Shukla *et al*. (2014) [23] reported that total biomass stored in the teak stands was 1937.55 Mg/ ha, out of this above and below ground contribution was 1685.38 and 252.90 Mg ha, respectively. Reddy *et al*., (2014) [20] reported that total amount of carbon sequestered in teak plantation was significantly higher in 20-year plantations (330.00 t/ha) than in 15-year (108.53 t/ha) and 10-year plantations (70.27 t/ha). The carbon storage in teak was 872.77 Mg/ ha (Shukla *et al*. 2014) [23]. Aggarwal and Chauhan, (2014) [1] reported a carbon sequestration rates of 2.64 t C ha^{-1} yr^{-1} in *T. bellirica*.

Racelis *et al*., 2019 [18]. reported a total biomass production of 1,120 Mg/ ha in *S. macrophylla* which is equivalent to 542 Mg ha^{-1} of C and 1,989 Mg ha^{-1} of CO_2. The total biomass in Mahogany (*Swietenia macrophylla*) woodlot plantations ranged between 52.48 and 824.44 Mg ha^{-1}. The average total biomass was 287.86 ± 22.64 Mg ha^{-1}. The average carbon stock in Mahagony plantation was estimated to 143.93 ±11.32 Mg ha^{-1} ranging between 26.24 Mg ha^{-1} and 412.22 Mg ha^{-1} (Pitol *et al*., 2018) [17].

Singh *et al*., (2016) [25] reported that in tropical dry deciduous forest the aboveground biomass of trees ranged from 37.93 to 63.73 Mg ha^{-1} and the belowground biomass from 11.12 to 17.81 Mg ha^{-1}. The total carbon pool ranged between 33.61 to 52.59 Mg ha^{-1}. The above ground biomass of tropical dry forests of northern India has been reported to range from 38.6 - 239.8 Mg ha^{-1} (Singh and Singh, 1991) [24]. For the tropical deciduous forests of Central India, aboveground biomass ranged from 31.8 Mg ha^{-1} to 20.7 Mg ha^{-1} (Salunkhe *et al*. 2016) [21]. Lal and Singh (2000) [10] estimated an average carbon stock of 31.72 Mg C ha^{-1} in Indian forests.

Chandana *et al*. 2020 [4] reported that AGB ranged between 42.7 and 59.5 t ha^{-1}, *in Melia dubia* with a mean of 51 t ha^{-1}. BGB varied from 11.1 to 14.9 t ha^{-1}, with an average of 13.3 t ha^{-1}. Total biomass varied from 53.9 to 74.9 t ha^{-1}. Similar findings were reported by Saravanan *et al*. 2013 [22] in *M. dubia*. Average carbon sequestration potential in melia based agri-silviculture system was found to be 118 t ha^{-1} under rainfed conditions.

Naik *et al*. (2019) [12] reported total biomass carbon in a 10-year-old mango orchard was 3.87Mg ha^{-1}. The carbon mitigation potential was highest with 3.0 Mg ha^{-1} with a corresponding carbon dioxide mitigation of 11.04Mg ha^{-1}in hot and sub-humid climate. The total standing aboveground biomass and belowground biomass of *Mangifera indica* were 82.83 t/ha and 21.54 t/ha respectively. The sequestered carbon stalk in aboveground and belowground standing biomass of *Mangifera indica* are 44.73 t/ha and 11.63 t/ha respectively (Chavan and Rasal, 2012) [5].

Table 2: SOC (Mg C/ha) as influenced by different land use system and soil depths

Land use system	Soil depth				
	0-20 cm	20-40 cm	40-60 cm	Mean	Total
T. grandis	23.24	14.97	7.96	15.39b	46.18
T. bellirica	19.93	12.24	9.44	13.87ab	41.61
S. macrophylla	30.83	13.44	8.05	17.44b	52.33
A. hirsutus	15.40	10.85	7.94	11.40a	34.19
Natural forest	37.69	19.37	19.70	25.59c	76.77
Horticulture	13.25	10.29	8.24	10.59a	31.77
Agroforestry	18.84	14.84	13.03	15.57b	46.71
Mean	22.74c	13.72b	10.62a		
	HSD (at 5%)	Sem			
Land use systems	3.95	0.901			
Depths	2.03	0.590			

Soil carbon sequestration

The carbon in the soil under Indian conditions is predominantly stored in the form of soil organic carbon and hence the quantification of soil carbon is expressed in terms of SOC. Soil organic carbon varied among the land use systems as well as at different soil depths (Table 2). Significantly highest SOC (Mg/ha) was recorded under natural forest (25.59 Mg/ha) followed by *S. macrophylla* (17.44 Mg/ha), agroforestry (15.57 Mg/ha) and *T. grandis* (15.39 Mg/ha) and it is lowest under horticulture (10.59 Mg/ha) followed by *A. hirsutus* (11.40 Mg/ha). At different soil depths, highest SOC was recorded under 0-20 cm (22.74 Mg/ha) and least under 40-60 cm (10.62 Mg/ha). Soil carbon plays a vital role in regulating climate, soil water availability, biodiversity, and providing many other services that are essential to human as well as environment wellbeing. Estimates of SOC stock has gained more importance in the light of global climate change in the recent turn of events (Yang *et al*. 2007) [27]. The soil carbon was assessed upto 60 cm soil depth and the soil carbon decreased with successive soil depths. Singh *et al*. (2016) [25] also reported decrease in soil carbon with soil depths. Soil organic matter is also a chief contributor to the carbon stocks of forests (Lal 2005, Kumar *et al*. 2006) [10, 9], next only to the aboveground biomass (Ravindranath and Ostwald, 2008) [19]. Brown *et al*. (1992) [2] reported that variations in the rate of SOC accumulation are due to the differences in species and environmental factors. Some species produce more litter and roots and thus, produce more organic inputs, which eventually influence soil carbon content. The soil organic carbon in tropical dry deciduous forest (Mg C ha^{-1}) was: 7.383 to 4.923 (0-15cm); 6.693 to 4.183 (15-30cm); 4.166 to 3.335 (30-45cm); 3.590 to 2.500 (45-60cm) (Singh *et al*., 2016) [25].

Table 3: Leaf litter carbon under different land use systems.

Land use system	Litter added (kg/ha/year)	Carbon added (kg/ha/year)	Carbon (Mg/ha/year)
T. grandis	2606.33	1156.69	1.16
T. bellirica	5318.76	2381.74	2.38
S. macrophylla	6339.29	2983.90	2.98
A. hirsutus	8988.94	3868.84	3.87
Natural	5286.83	2281.27	2.28
Agroforestry	-	-	-
Horticulture	-	-	-

Leaf litter carbon

The leaf litter added varied between the land use systems and highest litter was added under *A. hirsutus* (Table 3). The litter carbon was highest under *A. hirsutus* (3.87 Mg/ha/year) and lowest under *T. grandis* (1.16 Mg/ha/year). The carbon storage in leaf litter was 3.04 Mg/ ha in teak (Shukla *et al*., 2014) [23].

Table 3: Total amount of carbon and CO_2 sequestered by different land use system and its economic value.

Land use	Carbon pool (Mg ha^{-1})			Total carbon (Mg ha^{-1})	Total CO_2 (Mg ha^{-1})
	Tree Carbon	Soil carbon	Leaf litter carbon		
T. grandis	213.43	46.18	1.16	260.77	955.20
T. bellirica	414.87	41.61	2.38	458.86	1680.80
S. macrophylla	323.57	52.33	2.98	378.88	1387.84
A. hirsutus	868.70	34.19	3.87	906.76	3321.46
Natural forest	81.43	76.77	2.28	160.48	587.84
Horticulture	34.85	31.77	-	66.62	244.03
Agroforestry	53.64	46.71	-	100.35	367.58

Total carbon pool

The total carbon sequestered from all the three major carbon pools (standing tree biomass, litter, root and soil) from different land use system recorded variations (Table 4). The highest total carbon pool was recorded under *A. hirsutus* (906.76 Mg/ha) and least under horticulture system (85.41 Mg/ha).

The leaf litter was only estimated in four tree plantations and natural forest, therefore litter carbon was not determined in agroforestry and horticulture systems. Higher tree carbon stock in the tree plantations is recorded compared to other land use systems, and this is because of higher tree density seen in the (2500 trees/ha) tree plantations. Total carbon pool accumulated in *T. grandis* including soil, litter and standing biomass is 911.27 Mg/ ha (Reddy *et al*., 2014) [20]. Olorunfemi *et al*. (2020) [13] found that forest had highest overall carbon storage (249.23 Mg C ha^{-1}) followed by tree plantations (141.25 Mg C ha^{-1}), woodlands (96.37 Mg C ha^{-1}) and the least in crop lands (85.56 Mg C ha^{-1}). Kraenzel *et al*., estimated an average tree plantation level carbon storage as 120 t/ha. Litter, undergrowth and soil compartments were estimated to contain 3.4, 2.6 and 225 t C/ha, respectively.

The CO_2 sequestered varied between the land use systems (Table 3 and Fig. 3). The highest CO_2 was sequestered under *A. hirsutus* (3321.44 Mg ha^{-1}) followed by *T. bellirica* (160.80 Mg ha^{-1}) and least under horticulture system (469.36 Mg ha^{-1}).

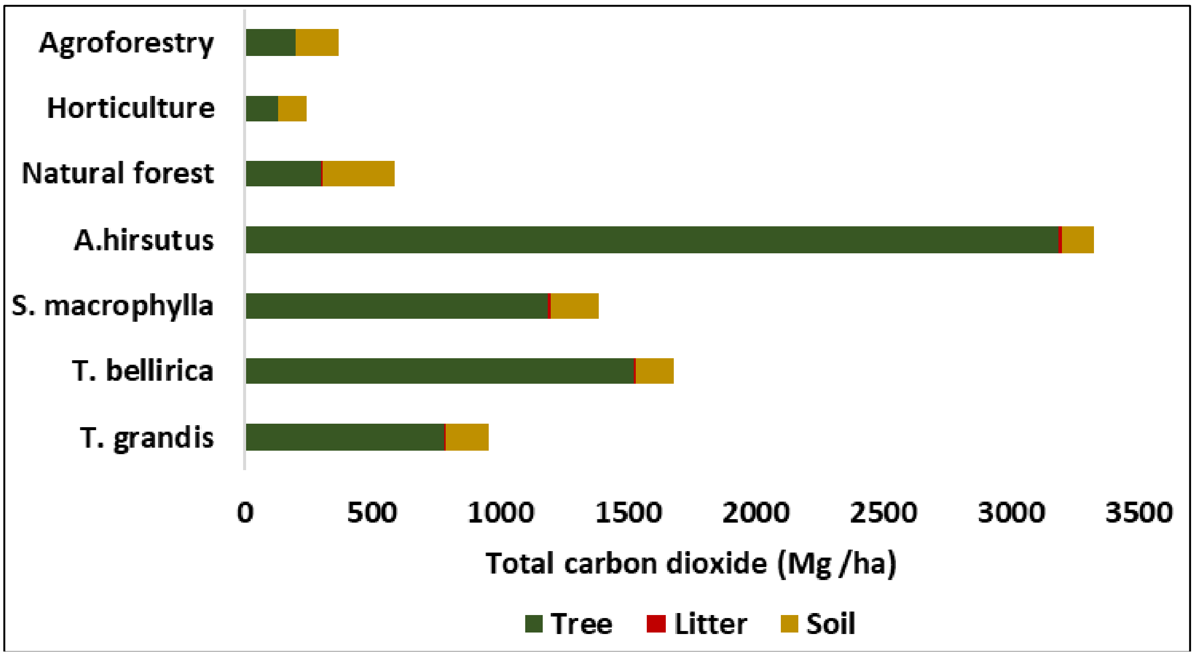

Fig 3: Total carbon dioxide pool in different land use systems

Conclusion

In this study we could find that different tree based system sequester carbon at varying scale. The mainly determining factors was the species, spacing and age of the plantations. The older and closer spaced tree plantations sequestered higher carbon. The CO_2 sequestered in tree biomass on a hectare basis was recorded highest under *A. hirsutus* followed by *T. bellirica*. Whereas the lowest CO_2 was sequestered under horticulture system followed by agroforestry. Highest SOC was recorded under natural forest and lowest under horticulture. The highest total CO_2 was sequestered under *A. hirsutus* followed by *T. bellirica* plantations and least under horticulture system. The trees are the best bet against the climate changing scenario. Therefore, we can conclude that promoting tree based system will help in mitigating the climate change.

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