International Journal of Multidisciplinary Research and Technology
ISSN 2582-7359, Peer Reviewed Journal, Impact Factor 6.325
www.ijmrtjournal.com

DEVELOPMENT OF ALLOMETRIC EQUATIONS FOR ESTIMATION OF BIOMASS AND CARBON STOCK IN *ACACIA MANGIUM* BASED AGROFORESTRY SYSTEM IN ODISHA, INDIA

[1]Debasmita Maharana, [2]Prasannajit Mishra, [3]Manas Ranjan Nayak, [4]Bibhuti Bhusan Behera
[5]Arun Kumar Handa
[1,2,3,4]AICRP on Agroforestry, OUAT, Bhubaneswar
[5]ICAR-CAFRI, Jhansi

Abstract

The experiment was conducted at the Odisha University of Agriculture and Technology's All India Co-ordinated Research Project on Agroforestry experimental site in Bhubaneswar, Odisha consisting of eight different land use systems viz., *Acacia mangium* + Pineapple, *Acacia mangium* + Aloe vera, *Acacia mangium* + Mango ginger, *Acacia mangium* + Kalmegh, *Acacia mangium* + Hybrid napier, *Acacia mangium* + Thin napier, *Acacia mangium* + Guinea grass and sole *Acacia mangium* plantation in randomized block design with three replications. *Acacia mangium* with kalmegh system at 138 months after planning recorded highest In comparison to other land use systems, *Acacia mangium* with the Kalmegh system saw the highest growth parameters 138 months after planning, including DBH (26.79 cm), basal area (0.06 m2), height (20.55 m), crown spread (5.58 m), crown depth (9.89 m), and volume (0.26 m3). In comparison to other land use systems, the Acacia mangium + Thin napier Silvipastural system produced the most biomass overall (21261.60 t/ha), carbon stock (197.02 t/ha), and CO2 assimilation (723.06 t/ha). However, the solitary *Acacia mangium* plantation had the lowest carbon stock (80.04 t/ha), CO2 assimilation (293.75 t/ha), and total biomass output (141.68 t/ha). The carbon content and biomass of the various portions of the *Acacia mangium* tree were estimated using allometric equations that showed a strong link with the tree's changing breast height diameter in relation to site and species. According to the results, combining thin Napier with *Acacia mangium* in an agroforestry silvipastural system has a higher capacity to store atmospheric carbon and seems like a workable way to lessen the consequences of climate change.

Keywords: *Acacia mangium,* Agroforestry, Biomass, Carbon Stock, Allometric equation.

Introduction:

Changing land use patterns are one of the factors causing the atmospheric carbon dioxide (CO2) to rise globally. Between 1950 and 2014, the atmospheric concentration of CO2 increased from 310 parts per million to above 400 parts per million (IPCC, 2014). According to the IPCC (2000), 17.4% of worldwide emissions of greenhouse gases (GHGs) are attributed to tropical deforestation and forest degradation. Agroforestry, afforestation, reforestation, and natural forest regeneration are examples of land use practices that lower CO_2 concentrations (Ghosh and Mahanta, 2014; Chaturvedi et al., 2016). Because it may be used in both reforestation initiatives and agricultural lands, agroforestry has been identified as a particularly significant carbon sequestration approach (Ruark et al., 2003; Roy, 2016). This system has become more functioning as a result of forestry and agroforestry's contributions to lowering the rate of GHG emissions and atmospheric CO_2 concentration (Mutuo et al., 2005).

By combining food production with environmental benefits, a tree-based intercropping system is one of the best ways to absorb carbon and provide food for those who rely on lands for their livelihoods (Soto-Pinto et al., 2010). serving as a carbon sink in biomass and soil; this role can be further improved by avoiding carbon-releasing practices like deforestation or by employing land management strategies that increase the amount of carbon stored in plants and soil (Janzen, 2005). It is anticipated that expanding carbon storage in agroforestry systems will boost carbon accumulation in the biomass of trees that have been planted and supply slowly dissolving litter as inputs to preserve soil organic carbon (Montagnini and Nair, 2004).

Acacia mangium Wild is a fast-growing, evergreen Australian tree that was brought to India in the 1980s and is now recognized as a woodlot species and a component of the multi-strata agroforestry system there (Kumar, 2005). The wood is in high demand for furniture and other household uses. Additionally, the wood is utilized to make pulp and paper. Although *Acacia mangium* is widely used in the humid tropics (Kunhamu et al., 2010), there is a dearth of species-specific data about the production and allocation of biomass above and below ground, their carbon potential, and the overall productivity as influenced by various land use systems.

Since the Kyoto Protocol, agroforestry has gained increased attention as a way to reduce carbon emissions in both developed and developing nations. Nair et al. (2010) estimate that the amount of carbon stored in agroforestry ranges from 30 to 300 Mg C ha-1 down to 1 m in soil and from 0.29 to 15.21 Mg C ha-1 yr-1 aboveground. According to Dhyani et al. (2009), small-holding agroforestry systems in India have the potential to mitigate 1.5 to 3.5 Mg C ha-1. However, it is also widely acknowledged that the mitigating capabilities would surely be impacted by the species, edaphic, climatic, and land use features of a particular location. Therefore, it is crucial to find location-specific appropriate land use systems that both meet the goal of carbon reduction and fit into the social-economic framework of society before developing region-specific policies. The return from the changed land use system after carbon credits are included will determine whether a farmer chooses to adopt a certain land use system. Numerous agroforestry studies have recently been carried out to look into compatibility in connection to the storage of carbon stocks (Rajput et al., 2015; 2016). Therefore, it is vital to evaluate the environmental suitability and carbon storage capacity of agroforestry systems in order to ascertain their relative importance in the current competition with other land use systems. The current study was carried out in *Acacia mangium*-based agroforestry systems to assess the biomass and carbon stocks.

Material & methods:

Site Condition: A trial was conducted at the experimental site of the All India Co-ordinated Research Project on Agroforestry at Odisha University of Agriculture and Technology in Bhubaneswar. The location has a tropical climate with moderate winters and steamy summers. The region's mean monthly minimum and maximum temperatures ranged from 15.0°C - 26.9°C and 29.70°C - 38.80°C, respectively. During the study period, there were 96 rainy days with an average yearly rainfall of 1403.6 mm. The soil at the study site ranged in texture from sandy loam to loamy sand.

Trial and maintenance: The experiment was arranged in Randomize Block Design with three replications. The experiment was on an agroforestry system which consists of silvicultural species such as *Acacia mangium* at spacing 8m x 2m and six agricultural species such as pineapple, aloe vera, mango ginger, hybrid napier, thin napier and guinea grass along with sole *Acacia mangium* as control. According to the layout plan, the experimental plot was divided into 16 m x 6 m plots for each treatment (Fig.1). 10 t/ha of well-decomposed FYM was applied after the land was ready. A typical dose of 25-50-50 kg of N-P2O5-K2O per acre was applied using urea, Diammonium Phosphate (DAP), and Murate of Potash (MOP).

Growth and Biomass Recording: Growth parameters i.e. height and diameter were recorded at six monthly interval since planting of trees. For diameter the colar diameter was recorded upto 30 months and then diameter at breast height (height of 1.37 m) was recorded from 36 months onwards. At 138 months following planning, the plants' final basal area, crown width, crown length, and stem volume (as determined by Newton's formula) were measured. The fresh weight of the stem, branch, and leaf biomass of the felled trees was recorded as soon as the tree was harvested in the field, and the dry biomass was recorded after the sample was oven-dried at 105^0 C at a constant temperature. Trees' root biomass was calculated by multiplying their above-ground biomass by a factor of 0.25 (IPCC, 2000 and Cairns et al., 1997). Subsamples of each replication were obtained and oven-dried at 60^0 C at a constant temperature after the intercrops were harvested, and the biomass of the intercrops was similarly recorded.

Carbon analysis: 50% of the dry biomass was identified as the carbon stock. Montagu et al. (2005), Irvin et al. (2012), and Losi et al. (2003). Using variable DBH, allometric equations were developed to predict the biomass, carbon stock, and stem volume of *Acacia mangium* trees for each tree component (stem, branch, and leaf). The following allometric relationship was utilized to apply the developed equation to every individual in the agroforestry system:

$$Wi = a\ D^b$$

Where a and b are co-efficient, D is tree diameter at breast height (cm), and Wi is the amount of carbon stock of component (kg) i or biomass of component i (kg) or stem volume (m3). The same species' biomass at other locations close to the test site can likewise be estimated using the coefficients. The amount of organic carbon in the soil was calculated using the conventional method (Walkley and Black, 1934). To estimate CO_2 assimilation, the carbon supply was multiplied by 3.67 (44/12) (Chhabra and Dadhwal, 2004 and Chauhan et al., 2009).

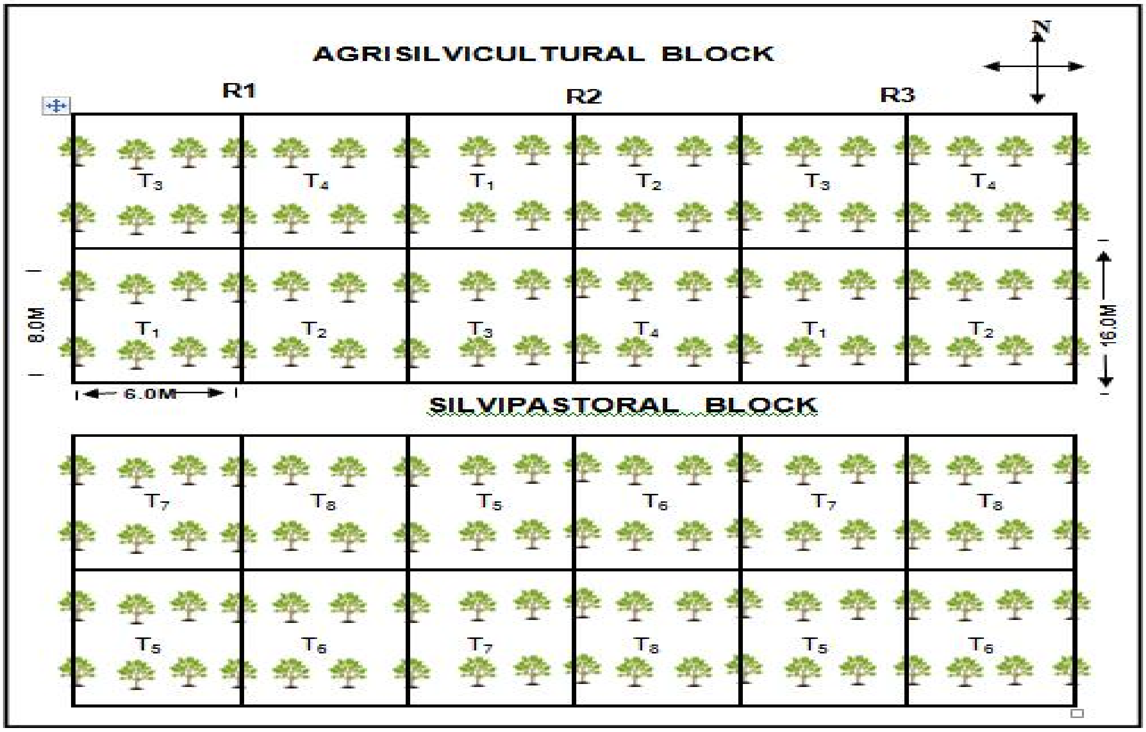

Fig. 1: Layout plan of experimental field

Results & discussion:

Tree Growth: The growth of *Acacia mangium* tree averaged over different agroforestry systems from planting to 138 months after planting recorded at six monthly interval is presented in Table -1 for giving an idea about general growth habit of *Acacia mangium* tree species with respect to height and diameter in this agro-climatic condition. As indicated in Table-2, the *Acacia mangium* with kalmegh system recorded highest growth parameters viz. DBH (26.79cm), basal area (0.06 m^2), height (20.55m), crown spread (5.58m), crown depth (9.89m) and volume (0.26 m^3) followed by other *Acacia mangium* based systems. The *Acacia mangium* with thin napier systems recorded lower growth parameters e.g. tree height, DBH, basal area. However, crown width of all system is statistically alike except *Acacia mangium* with thin napier which recorded the lowest value of 4.29m and significantly differ from all other systems. This may be due to higher competition by the intercrops through high green fodder production and removal of excess nutrient by the grasses in silvipastoral systems as also testified by several investigators Prasad *et al*. (2012), Kumar *et al*., (1998).

Table 1. Average growth pattern of *Acacia mangium* under different agroforestry systems

Months after Planting	Height (m)	DBH (cm)	Months after Planting	Height (m)	DBH (cm)
0	0.41	0.24*	72	14.03	16.33
06	1.27	1.71*	78	15.29	17.65
12	1.46	2.76*	84	15.50	18.32
18	3.70	5.70*	90	15.88	19.12
24	4.71	7.05*	96	16.10	19.74
30	6.79	9.24*	102	16.40	20.81
36	7.57	10.62	108	16.67	21.38
42	10.03	12.73	114	17.13	22.01
48	10.35	13.35	120	17.49	22.33

54	11.25	14.29	126	18.21	22.92
60	11.96	15.01	132	18.56	23.17
66	13.25	15.63	138	19.24	23.64

*Colar dia was recorded upto 30 months after planting

Allometric equations parameters: Allometric equations of *Acacia mangium* obtained from this investigation is reliable, however, the equations are created by applying diameter at breast height (DBH) ranged from 15.7 - 32.7cm (stem volume) and 17.3 - 34.6 cm (biomass and carbon) (Fig. 4 to 16). The allometric equations produced are as follows : $Y= 0.001 X^{1.695}$ $r^2 = 0.977$ (Stem volume), $Y= 0.071 X^{2.438}$ $r^2 = 0.974$ (stem biomass), $Y=0.029 X^{2.238}$ $r^2 = 0.952$ (branch biomass), $Y = 0.066 X^{1.967}$ $r^2 = 0.960$ (leaf biomass) $Y=0.141 X^{2.345}$ $r^2 = 0.981$ (above ground tree biomass), $Y = 0.035 X^{2.345}$ $r^2 = 0.981$ (root biomass), $Y=0.185 X^{2.330}$ $r^2 = 0.981$ (total biomass of tree), $Y=0.039 X^{2.437}$ $r^2 = 0.974$ (stem carbon), $Y=0.014 X^{2.281}$ $r^2 = 0.952$ (branch carbon), $Y = 0.031 X^{1.982}$ $r^2 = 0.960$ (leaf carbon) $Y = 0.070 X^{2.343}$ $r^2 = 0.981$(above ground tree carbon), $Y = 0.0.017 X^{2.343}$ $r^2 = 0.981$ (root carbon) and $Y = 0.088 X^{2.343}$ $r^2 = 0.981$ (total carbon of tree). These allometric equations are statistically robust and having a high correlation coefficient ($r^2 > 0.95$) in every equation. These equations can be used to estimate tree volume, biomass and carbon in similar agro ecological situations. During this allometry study, independent variables like height and density are not included which may have affected the accuracy of estimate equation. However, Kauffman and Donato (2012) reported that wood density, tree height is likely to yield greater accuracy equations. Therefore, while estimating biomass by using DBH values beyond diameter interval of this study should be avoided to maintain the accuracy of the estimation.

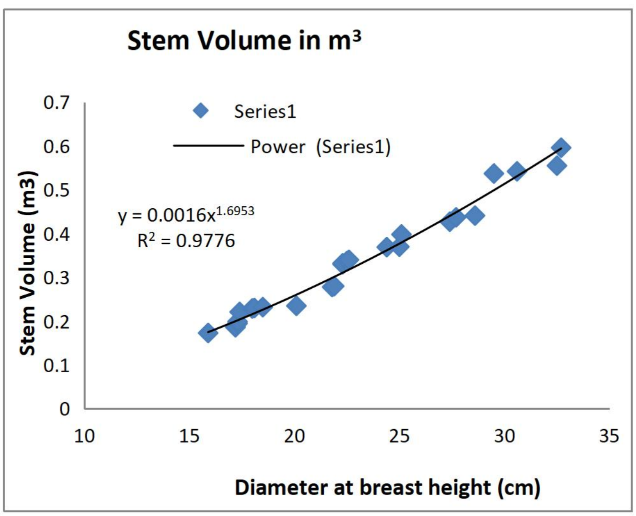

Fig.4: Allometric equation showing relationship between of volume(m^3) and diameter at breast height (cm)

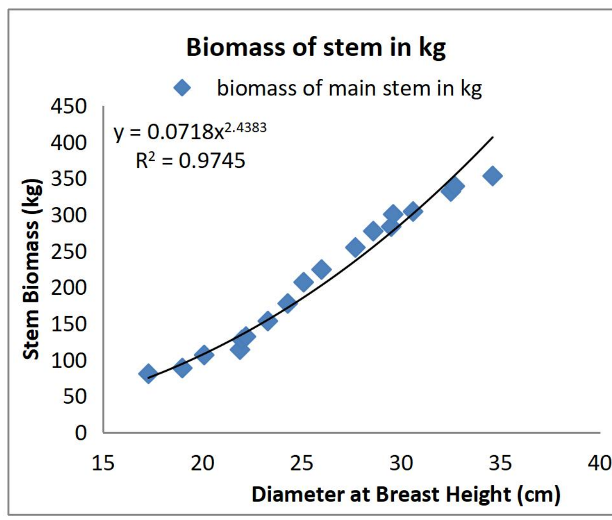

Fig.5: Allometric equation showing relationship between of Stem Biomass (kg) and Diameter at Breast Height(cm)

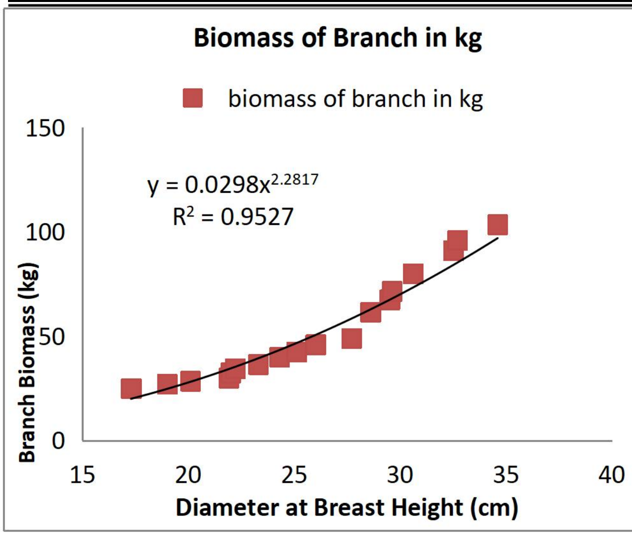

Fig.6: Allometric equation showing relationship between of branch biomass (kg) and diameter at breast height(cm).

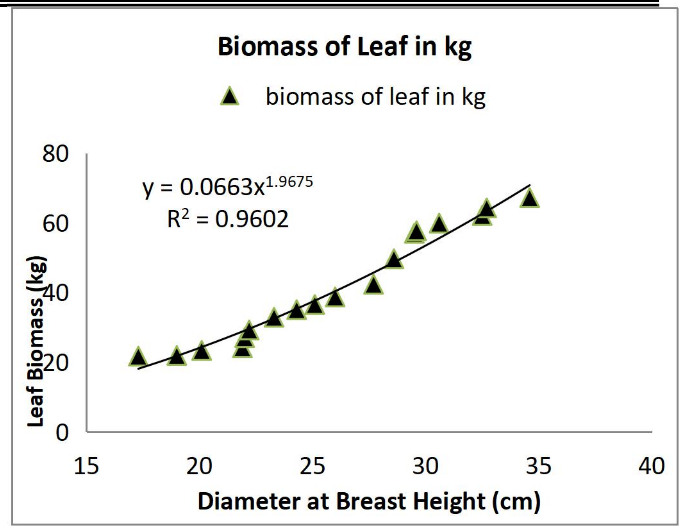

Fig.7: Allometric equation showing relationship between of leaf biomass (kg) and diameter at breast height (cm).

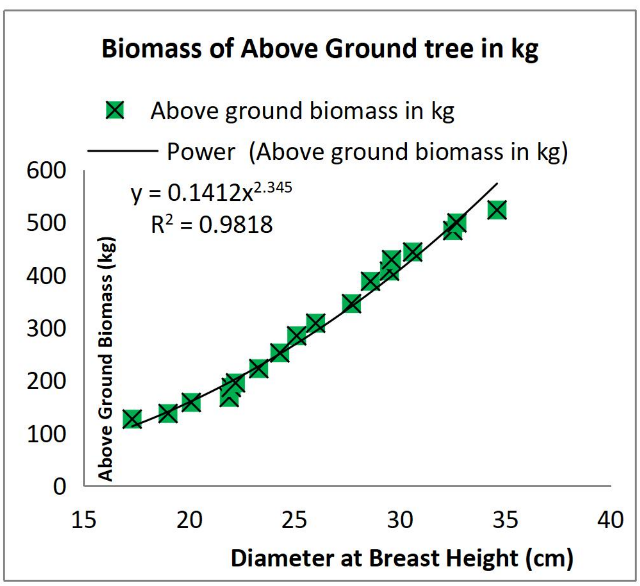

Fig.8: Allometric equation showing relationship between of above ground biomass (kg) and diameter at breast height (cm).

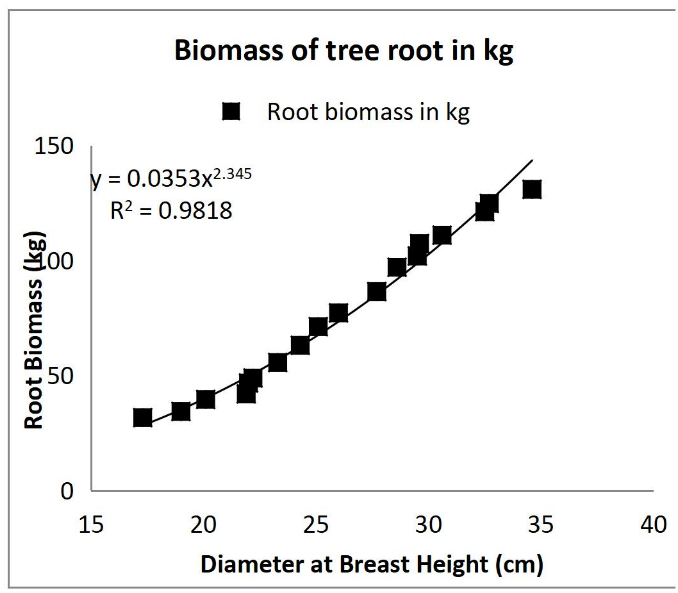

Fig.9: Allometric equation showing relationship between of tree root biomass (kg) and diameter at breast height (cm).

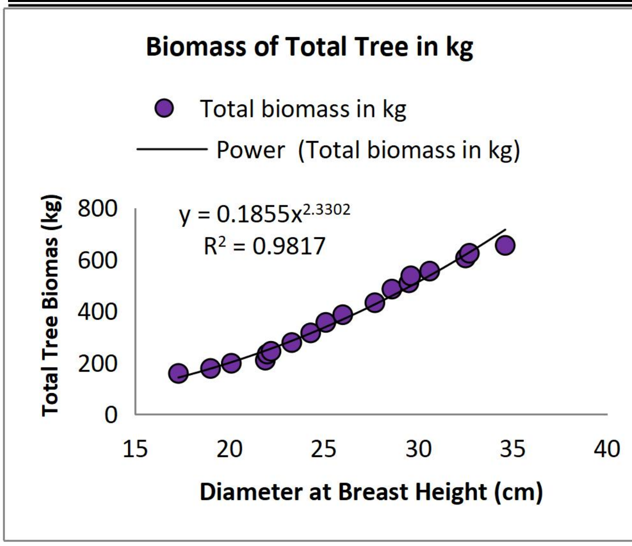

Fig.10: Allometric equation showing relationship between of total tree biomass (kg) and diameter at breast height (cm).

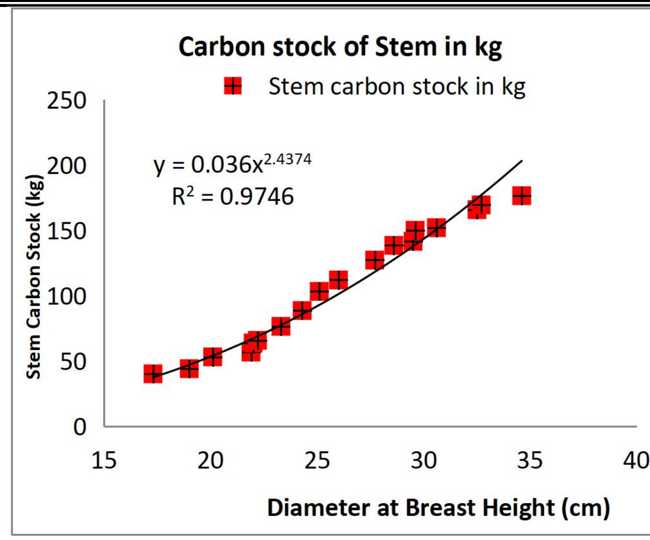

Fig.11: Allometric equation relationship between of stem carbon (kg) and diameter at breast height (cm).

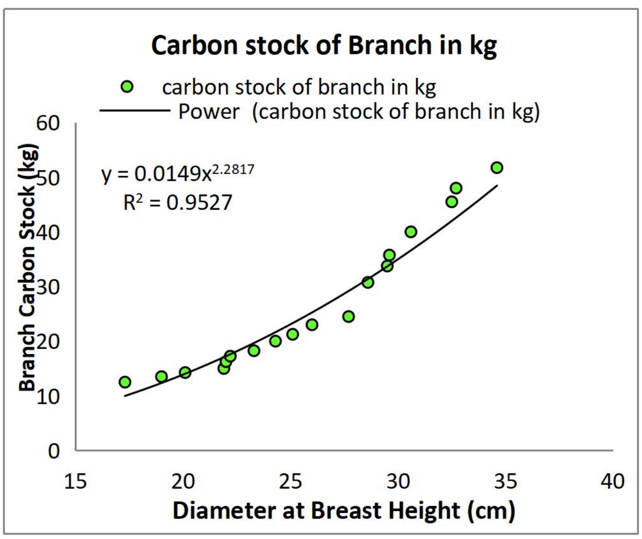

Fig.12: Allometric equation showing relationship between of branch carbon (kg) and diameter at breast height (cm).

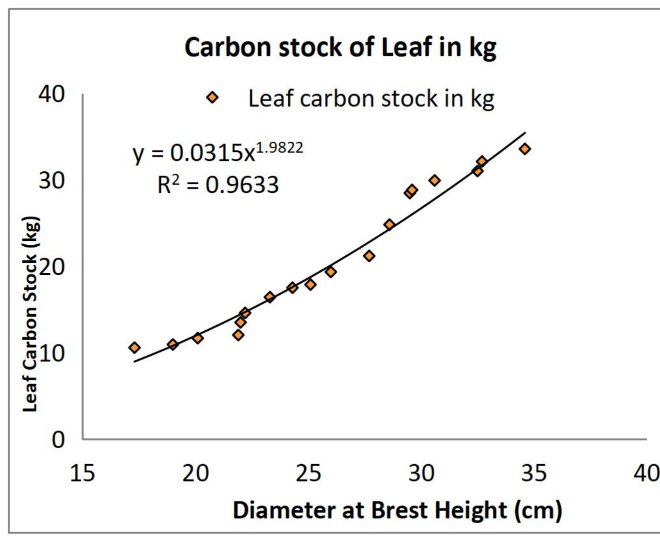

Fig.13: Allometric equation showing relationship between of leaf carbon (kg) and diameter at breast height (cm).

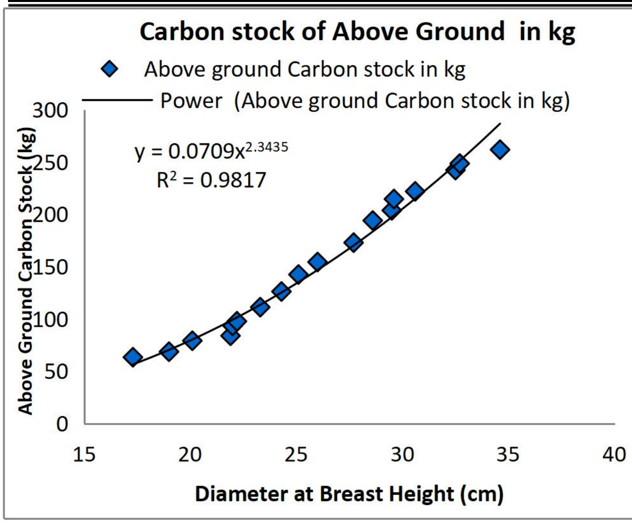

Fig.14: Allometric equation showing relationship between of above ground carbon (kg) and diameter at breast height (cm).

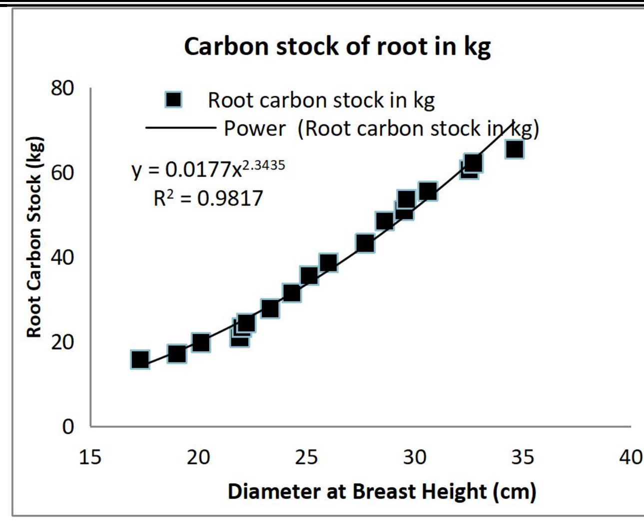

Fig.15: Allometric equation showing relationship between of root carbon (kg) and diameter at breast height (cm).

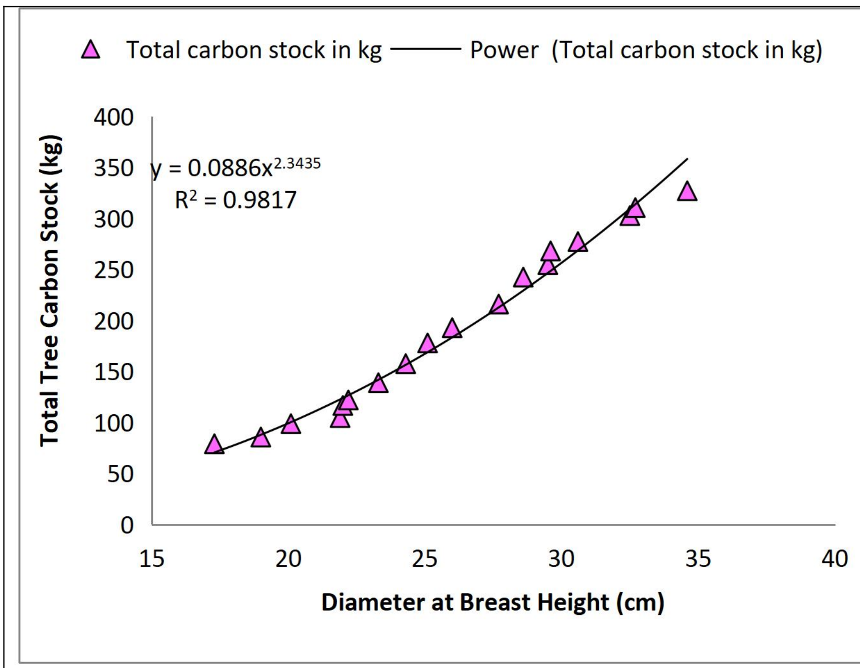

Fig.16: Allometric equation showing relationship between of total carbon (kg) and diameter at breast height (cm).

Table.2: Growth performance of *Acacia mangium* under agroforestry systems

Treatment	DBH (cm)	Basal Area (m^2)	Height (m)	Crown Width (m)	Crown length (m)	Volume (m^3/tree)
Acacia mangium + Pineapple	26.42	0.05	20.31	5.28	9.72	0.26
Acacia mangium + *Aloe vera*	22.73	0.04	19.6	5.26	9.01	0.20
Acacia mangium + Mango ginger	24.30	0.05	19.26	5.44	9.11	0.22
Acacia mangium + Kalmegh	26.79	0.06	20.55	5.58	9.89	0.26

Acacia mangium + Hybrid napier	22.23	0.04	18.80	5.12	8.34	0.19
Acacia mangium + Thin napier	21.4	0.04	18.02	4.89	7.81	0.18
Acacia mangium + Guinea Grass	20.69	0.03	18.04	4.29	7.76	0.17
Control	22.67	0.04	18.69	5.22	8.68	0.20
CD at 5%	2.988	0.011	2.478	1.145	2.529	0.045
CV	7.29	14.20	7.37	12.73	16.43	12.19

Biomass of *Acacia mangium* trees under agroforestry systems: The biomass and stem volume of *Acacia mangium* under eight different regimes are shown in Table 3. The highest stem volume is found in *Acacia mangium* with kalmegh system (131.72 m^3 ha^{-1} and MAI 10.13 m^3/yr/ha) which is at par with *Acacia mangium* in combination with pine apple or mango ginger systems and significantly higher than other systems. *Acacia mangium* with guinea grass system produced lowest stem volume of 87.42 m^3 ha^{-1} and MAI 6.72 m^3/yr/ha which is even lower than sole *Acacia mangium* plantation. Stem volume of *Acacia mangium* varies from 6.72-10.31 m^3 ha^{-1} yr^{-1}. Similar findings were also reported by Torres and Santo (2007), Wadsworth (1997), Udarbe (1987) and Herianysa *et al.(*2007). Dry weight of stem, branch and leaf of trees are found 44%, 49% and 27% to fresh weight respectively. Whereas, stem, branch and leaf contribute 69%, 17% and 14% biomass to above ground biomass of tree. Acacia mangium's aboveground biomass components consist of roughly 55 to 80% stems, 10 to 22% branches, 7 to 10% bark, and 2 to 9% leaves, according to Krisnawati et al. (2011). Each component's percentage contribution to the tree's overall weight varies significantly as well; the leaf contributes between 1.9 - 10.6%, the branch between 8.0 - 39%, and the stem between 55.6 - 87.9%. Herianysa et al. (2007) and Ilyas (2013) also note similar results. This indicates biomass production in the order of stem>branch>leaf which is observed in all the eight agroforestry systems. *Acacia mangium* with kalmegh system found to have highest stem, branch and leaf biomass viz-107.74 t/ha, 26.25t/ha and 21.27t/ha respectively, followed by *Acacia mangium* with pineapple and *Acacia mangium* with mango ginger systems which are at par with each other, while *Acacia mangium* with guinea system recorded the lowest biomass of stem (71.74 t/ha), branch (17.94 t/ha) and leaf (13.23 t/ha). The total above ground tree biomass in systems ranged from 88.34–155.26 t/ha with *Acacia mangium* with kalmegh system recorded the highest tree biomass with annual biomass production of 11.94 t/ha/year and lowest value is found in *Acacia mangium* with guinea grass system having annual biomass production of 6.79 t/ha/year.

Table.3: Biomass storage in different components of *Acacia mangium* trees under agroforestry systems

Treatment	DBH (cm)	Stem Volume (m^3ha^{-1})	Stem Biomass (t/ha)	Branch Biomass (t/ha)	Leaf Biomass (t/ha)	Total (t/ha)
Acacia mangium + Pineapple	26.42	128.76	104.38	25.48	20.72	150.59
Acacia mangium + Aloe vera	22.73	99.75	72..28	18.07	15.41	105.75
Acacia mangium + Mango ginger	24.3	111.9	85.53	21.14	17.62	124.29
Acacia mangium + Kalmegh	26.79	131.72	107.74	26.25	21.27	155.26
Acacia mangium + Hybrid napier	22.23	96.26	68.94	17.27	14.8	101.02
Acacia mangium + Thin napier	21.4	90.31	62.67	15.8	13.71	92.19
Acacia mangium + Guinea grass	20.69	87.42	59.95	15.16	13.23	88.34
Control	22.67	99.25	71.74	17.94	15.32	105
CD at 5%	2.988	22.396	24.16	5.617	3.362	33.859
CV	7.29	11.08	17.43	16.33	10.98	16.77

Total biomass of Acacia mangium based agroforestry systems: The *Acacia mangium* with thin napier is found to produce the highest intercrops biomass (261.60 t/ha). Higher biomasses of intercrops are recorded in silvipastoral systems in comparison to agrisilvicultural systems. Root biomass of *Acacia mangium* is found highest with kalmegh system (38.82 t/ha) followed by *Acacia mangium* with pine apple (37.65 t/ha) and *Acacia mangium* with mango ginger (31.07 t/ha) system and minimum root biomass found in *Acacia mangium* with guinea grass system (22.09 t/ha). The total biomass of the agroforestry systems varied from 141.68-376.84 t/ha, the highest biomass found in Acacia mangium with thin napier followed by Acacia mangium with guinea system and lowest biomaas found in sole *Acacia mangium* (Table-4). This is due to addition of higher intercrop biomass in *Acacia mangium* with thin napier system and was similar to the observations of (Ilyas (2013); Herianysa *et al.* (2007); Torres and Santo (2007); Marilyn *et al.* (2011) and Brown (1997).

Table.4: Total biomass of *Acacia mangium* based agroforestry systems

Treatment	Above ground biomass of tree (t/ha)	Intercrops biomass (t/ha)	Total Above Ground biomass (t/ha)	Root biomass of tree (t/ha)	Total biomass (t/ha)
Acacia mangium + Pineapple	150.59	59.17	209.74	37.65	247.39
Acacia mangium + Aloe vera	105.75	32.67	138.42	26.44	164.86
Acacia mangium + Mango ginger	124.29	31.05	155.34	31.07	186.42
Acacia mangium + Kalmegh	155.26	31.03	186.30	38.82	225.10
Acacia mangium + Hybrid napier	101.02	215.24	316.26	25.25	341.51
Acacia mangium + Thin napier	92.19	261.60	353.79	23.05	376.84
Acacia mangium + Guinea grass	88.34	260.95	349.26	22.09	371.34
Control	105.00	10.43	115.43	26.25	141.68
CD at 5%	33.859	9.651	35.753	8.464	43.966
CV	16.77	4.89	8.95	16.77	9.77

Carbon stock in Acacia mangium trees under agroforestry systems: Stem, branch and leaf contribute 69%, 17% and 14% carbon to above ground carbon of tree. This represents trend of carbon production in the order of stem>branch>leaf which is followed in all the eight agroforestry systems. *Acacia mangium* with kalmegh system found to have highest stem, branch and leaf carbon viz-53.87 t/ha, 13.13 t/ha and 10.63 t/ha respectively followed by *Acacia mangium* with pineapple and *Acacia mangium* with mango ginger systems which are at par with each other, while *Acacia mangium* with guinea system recorded the lowest carbon of stem (29.98 t/ha), branch (7.58 t/ha) and leaf (6.61 t/ha) (Figure-2). The systems' total above-ground tree carbon content varied between 44.17 and 77.63 t/ha. *Acacia mangium* with kalmegh system recorded the highest tree carbon content with annual carbon storage of 3.39 t/ha/year and lowest value is found in *Acacia mangium* with guinea grass system having annual carbon storage of 5.97 t/ha/year.

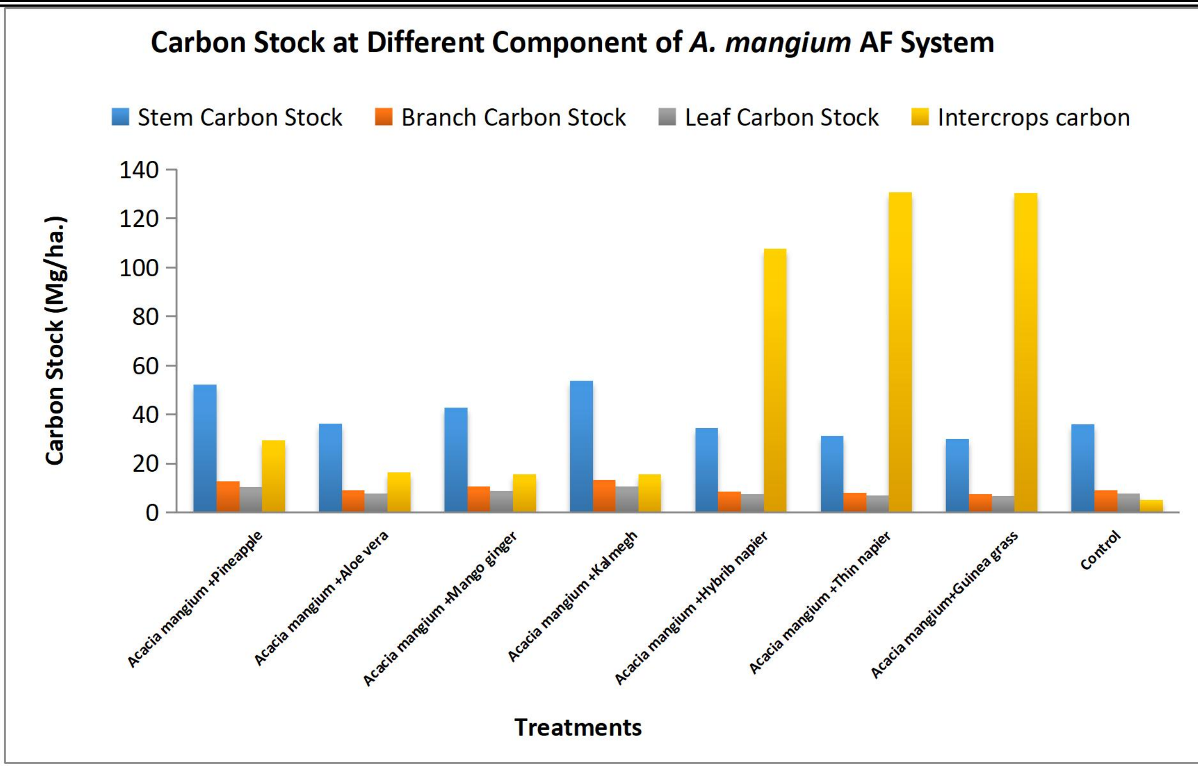

Fig. 2: Carbon stock in different components of *Acacia mangium* trees under agroforestry systems

Carbon stocks in whole biomass of Acacia mangium based agroforestry systems: Higher intercrops carbon is recorded in silvipastoral systems in comparison to agrisilvicultural and sole *Acacia mangium* systems (Fig.3). *Acacia mangium* with thin napier is found to produce the highest intercrops carbon (130.80 t/ha). Root carbon of *Acacia mangium* is found highest with kalmegh system (19.41 t/ha) followed by *Acacia mangium* with pine apple (18.82 t/ha) and *Acacia mangium* with mango ginger (15.54 t/ha) system and minimum root carbon is found in *Acacia mangium* with guinea grass system (11.04 t/ha). The agroforestry systems' total carbon content ranged from 70.74 to 188.42 t/ha; the Acacia mangium with thin napier had the highest carbon content, followed by the Acacia mangium with guinea, while the solitary Acacia mangium had the lowest carbon content. The generation of biomass in various systems is closely linked to the storage of carbon. The silvipastoral systems due to high green fodder production through multiple cuttings in a year than agrisilvicultural systems is responsible for high total carbon sequestration. Systems age (Albrecht and Kandji 2003), structure and function (Albrecht and Kandji 2003), silvicultural management (Vogt et al. 1996; Albrecht and Kandji 2003; Peichl et al. 2006), climate (Rao et al. 1998), soil characteristics like texture and clay properties (Batjes 1999), and land-use history (Tian et al. 2005) are a few of the elements that research links to the quantity of carbon stored in an ecosystem.

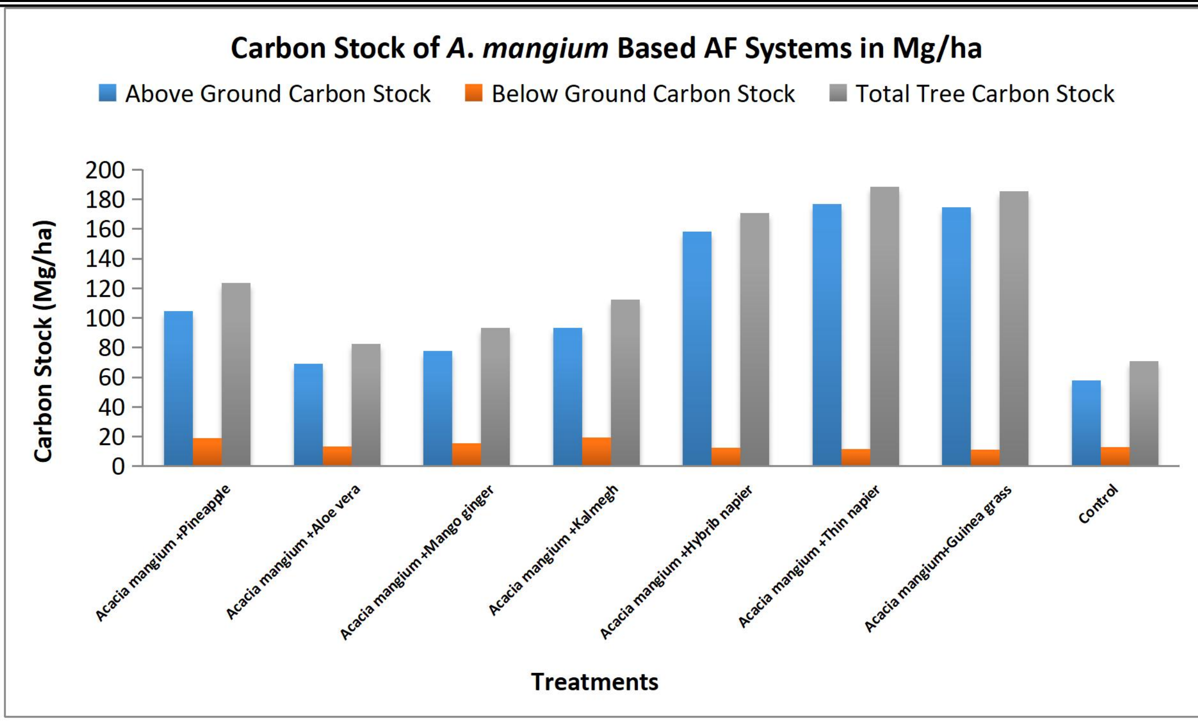

Fig. 3: Total carbon stock in different components of *Acacia mamgium* trees under agroforestry systems.

Total carbon stock in agroforestry systems: The highest carbon storage in soil is found in *Acacia mangium* with kalmegh system (12.6 t/ha) and lowest in *Acaciam mangium* with Hybrid napier (9.0 t/ha) (Table 5). The total carbon (including soil) in these systems varied from 80.04- 197.02 t/ha with highest carbon storage in Acacia mangium with thin napier and lowest in sole Acacia mangium. Thus, the trend of total carbon accumulation in the agroforestry system is found in the following order: Acaia mangium + thin napier > Acacia mangium + guinea grass> Acacia mangium + hybrid napier> Acacia mangium + pineapple> Acacia mangium + kalmegh> Acacia mangium + mango ginger> Acacia mangium + *Aleovera*> control system. However, the structure and function of the many components within the systems put into practice determine how much C is present in any given agroforestry system (Schroeder 1994; Prasad et al. 2011).

Table.5: Total carbon sequestration by *Acacia mamgium* based agroforestry systems

Treatment	Total Biomass (t/ha)	Total carbon of tree and intercrops (t/ha)	Soil organic cabon (2013) (t/ha)	Total carbon (t/ha)	CO_2assimilation (t/ha)
Acacia mangium + Pineapple	247.39	123.70	11.8	135.5	497.29
Acacia mangium + *Aloe vera*	164.86	82.43	9.6	92.03	337.75
Acacia mangium + Mango ginger	186.42	93.21	9.2	102.41	375.84
Acacia mangium + Kalmegh	225.10	112.55	12.6	125.15	459.30
Acacia mangium + Hybrid napier	341.51	170.71	9.0	179.71	661.74
Acacia mangium + Thin napier	376.84	188.42	8.6	197.02	723.06
Acacia mangium + Guinea grass	371.34	185.69	10.2	195.89	718.92
Control	141.68	70.74	9.3	80.04	293.75

Conclusions:

From the results, it is concluded that, *Acaia mangium* trees in agrisilvicultural systems recorded higher growth rate in comparison to its sole plantation and this sole plantation is also found higher than silvipastoral systems. Among the agroforestry systems, *Acacia mangium* trees in combination with kalmegh crop grow faster than *Acacia mangium* trees in others systems. The *Acacia mangium* based agroforestry system has a greater potential in biomass and carbon sequestration than sole crops. Comparatively speaking, silvipastoral systems sequester more carbon and produce more biomass overall than agrisilvicultural systems. The Acacia mangium with thin napier had the highest total biomass and carbon of all the systems. The carbon content and biomass of the various portions of the Acacia mangium tree were evaluated using allometric equations that showed a strong association with the tree's changing breast height diameter in relation to site and species. In other agroforestry systems with comparable agro-ecological circumstances, this equation can also be applied.

References:

1. Albrecht, A. and Kandji, S.T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment* 99: 15–27.
2. Batjes, N.H. 1999. Management options for reducing CO_2- concentrations in the atmosphere by increasing carbon sequestration in the soil. NRP report: 410-200-131, International Soil Reference and Information Centre, Wageningen.
3. Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer UN FAOForestryPaper134,Rome,55pp.http://www.fao.org/docrep/W4095E/W4095E00.htm
4. Cairns, M., Brown, S., Helmer, E. and Baumgardner, G. 1997. Root biomass allocation in the world's upland forests. *Oecologia,* 111:1–11.
5. Chaturvedi, O.P., Handa, A.K. Kaushal, R. Sarvade, S. and Panwar, P. 2016. Biomass production and carbon sequestration through agroforestry. *Range Management and Agroforestry,* 37: 116-127.
6. Chauhan, S.K. Gupta, N. Yadav, R.S. and Chauhan, R. 2009. Biomass and carbon allocation in different parts of agroforestry tree species. *Indian Forester,* 135: 981-993.
7. Chhabra, A. and Dadhwal, V.K. 2004. Assessment of major pools and fluxes of carbon in India. *Climate Change,* 64: 340-360.
8. Dhyani, S.K., Newaj, R. and Sharma, A.P. 2009. Agroforestry: its relation with agronomy, challenges and opportunities. *Indian J. Agron*., 54: 249–266.
9. Ghosh, P.K. and Mahanta, S.K. 2014. Carbon sequestration in grassland systems. *Range Management and Agroforestry,* 35: 173-181.
10. Heriansyah, I., Miyakuni, K., Kato, T., Kiyono, Y. and Kanazawa, Y. 2007. Growth Characteristics and Biomass Accumulations of *Acacia mangium* Under Different Management Practices in Indonesia. *Journal of Tropical Forest Science,* 19: 226–235.
11. Ilyas, S. 2013. Allometric Equation and Carbon Sequestration of *Acacia mangium* Willd. in Coal Mining Reclamation Areas**.** *Civil and Environmental Research,* 3 :1-16.
12. Intergovernmental Panel on Climate Change (IPCC) 2000. IPCC Special report on land use, land-use change and forestry. Special Report. Cambridge University Press, Cambridge, USA. (http://www.grida.no/publications/other/ipcc_sr/).
13. IPCC 2007. Climate change 2007: impacts, adaptation and vulnerability. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson (eds.). *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
14. IPPC 2014. Climate Change 2014: Mitigation of Climate Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.). *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, NY, USA.
15. Irvin, K. and Hussain, S.A.D.G.Y.A. 2012. Estimation Of Tropical Forest Biomass for Assessment of Carbon Sequestration Using Regression Models and Remote Sensing In Berau, East Kalimantan, Indonesia, Department of Natural Resources, The International Institute for Geoinformation Science and Earth Observation (ITC), Hengelosstraat 99, 7500 AA, Enschede, Netherlands.
16. Janzen, H. H. 2005. Soil carbon: a measure of ecosystem response in a changing world? Can. *J. Soil. Sci.,* 85:467–480.
17. Kauffman, J. B. and Donato, D. C. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.
18. Krisnawati, H., Kallio, M. and Kanninen, M. 2011. *Acacia mangium* Willd.: ecology, silviculture and productivity. CIFOR, Bogor, Indonesia.
19. Kumar, B. M. 1998. Bamboos in the homegardens of Kerala: A shrinking resource base. *Journal of non-timber Forest Products,* 4 :156-159.

20. Kumar, B. M. 2005. Litter dynamics in tropical plantation forests and agroforestry system, In: Soil Biodiversity, Ecological Processess and Landscape Management (eds, p.s. Ramakrishnan, K.G. Saxsena, M. J. Swift, K. S. Rao and R. K. Maikhuri). Mohan Primlani, New Delhi, pp. 85-111.

21. Kunhami, T. K., Kumar, B. M., Viswanathan, S. and Sureshkumar, P. 2010. Root activity of young Acacia mangium Wild trees: influence old stand density and pruning as studied by "p soil injection technique. Agrofor. System, 78: 27-38.

22. Losi, C. J., Siccama, T. G., Condit, R. and Morales, J. E. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. *Forest Ecology and Management,* 184: 355-368.

23. Marilyn, S., Combalicer., Lee, D. K., Woo, S. Y., Park, P. S., Lee, K. W., Tolentino, E. L., Combalicer, E. A., Lee Y. K. and Park, Y. D. 2011. Aboveground biomass and productivity of nitrogen-fixing tree species in the Philippines.*Scientific Research and Essays,* 6 :5820-5836.

24. Montagnini F. and Nair P. K. R. 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. *Agroforestry System,* 61: 281–295.

25. Montagu, K. D., Duttmer, K., Barton, C. V. M. and Cowie, A. L. 2005. Developing general allometric relationships for regional estimates of carbon sequestration--an example using Eucalyptus pilularis from seven contrasting sites. *Forest Ecology and Management,* 204: 115-129.

26. Mutuo P. K., Cadisch G., Albrecht A., Palm C. A. and Verchot L. 2005. Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. *Nutrient Cycling in Agroecosystems*, 71: 45-54.

27. Nair, P. K. R., Nair, V. D., Kumar, B. M. and Showalter, J. M. 2010. Carbon sequestration in agroforestry systems. *Adv. in Agro*., 108: 237-307.

28. Peichl, M., Thevathasan, N. V., Gordon, A., Huss, J. and Abohassan, R. A. 2006. Carbon sequestration potentials in temperature tree-based intercropping systems, southern Ontario, Canada. *Agroforestry Systems,* 66:243–257.

29. Prasad, J. V. N. S., Korwar, G.R., Rao, K.V., Srinivas, K., Srinivasarao, C., Pedababu B., Venkateswarlu, B., Rao, S. N. and Kulkarni, H. D. 2011. On-farm evaluation of two fast growing trees for biomass production for industrial use in Andhra Pradesh, Southern India. *New Forests*, 42:51–61.

30. Prasad, J. V. N. S., Korwar, G. R., Rao, K. V., Srinivas, K., Srinivasarao C., Pedababu B.,Venkateswarlu, B., Rao, S. N. and Kulkarni, H. D. 2011. On-farm evaluation of two fast growing trees for biomass production for industrial use in Andhra Pradesh, Southern India. *New Forests,* 42: 51–61.

31. Rajput, B. S., D. R Bhardwaj and N. A. Pala. 2015. Carbon dioxide mitigation potential and carbon density of different land use systems along an altitudinal gradient in north-western Himalayas. *Agroforestry System.* DOI 10.1007/s10457-015-9788-8 Springer.

32. Rajput, B. S., D. R. Bhardwaj and N. A. Pala. 2016. Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya. *Agroforestry System,* DOI 10.1007/s10457-016-9948-5.

33. Rao, M. R., Nair, P. K. R and Ong, C. K. 1998. Biophysical interactions in tropical agroforestry systems. *Agroforestry System,* 38: 3–50.

34. Roy, M. M. 2016. Agroforestry on dry and degraded lands: present status and future rospects. Range Management and Agroforestry, 37: 1-11.

35. Ruark, G. A., M. M. Schoeneberger and P. K. R. Nair. 2003. Agroforestry–helping to achieve sustainable forest management*. In: Proceedings of UNFF (United Nations Forum for Forests) Intercessional Experts Meeting on 'Role of Planted Forests in Sustainable Forest Management'*, March 24-30, 2003, New Zealand. www.maf.govt.nz/unff-planted-forestrymeeting.

36. Schroeder, P. 1994. Carbon storage benefits of agroforestry systems. *Agroforestry Systems,* 27:89 -97.

37. Soto-Pinto L., Anzueto M., Mendoza J., Ferrer G.J. and Jong B.D. 2010. Carbon sequestration through agroforestry in inswgenous community of Chiapas, Maxico. *Agroforestry System,* 78: 39–51.

38. Tian, G., Kang, B. T., Kolawole, G. O., Idinoba, P. and Salako, F. K. 2005. Long-term effects of fallow systems and lengths on crop production and soil fertility maintenance in West Africa. *Nutrient Cycle Agroecosystem,* 71:139–150.

39. Toress, S. and Santo, P. 2007. Estimating Biomass of tropical species. *New Forests,* 22: 23-49. DOI 20.1007/s11022-007-1056-5.

40. Udarbe, M. P. 1987. The future role of *Acacia mangiu*m in the timber, pulp and paper industry in Sabah, presented at the 41st Annual General Conference, Sydney, 409-411 pp.

41. Vogt L_tzow, M., K_gel-Knabner, I., Ekschmitt, K., Flessa, H., Guggenberger, G., Matzner, E., Marschner, B. 1996: SOM fractionation methods: Relevance to functional pools and to stabilization mechanisms. *Soil Biological Biochemistry,* 39: 2183–2207.

42. Walkley, A. and Black, I. A. 1934. An experiment of the Degtjareff method for determining soil organic matter and a proposal modification of the chromic acid titration method. *Soil Science,* 34: 29-38.

43. Wordsworth, M. A. 1997. Allometry and partitioning of above and below ground tree biomass in an age-sequence of *Acacia* Plantation. *Forest Ecological Management,* 253:68–80.