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Atmospheric carbon capturing potential of block plantations

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Abstract: Mixed-block plantation can be a good silvicultural alternative to large-scale sole block plantations for climate change mitigation, which is facilitated by the sequestration of atmospheric carbon dioxide. To evaluate the impacts of tree species compositions on the carbon storage capacity of plantation ecosystems, we measured the above and belowground biomass, as well as the carbon content, in three 20-year old sole block plantations of *Dalbergia sissoo*, *Tectona grandis* and mixed block plantation *D. sissoo* / *T. grandis* stands. We developed an allometric equation to estimate atmospheric carbon capturing capacity of trees. The carbon capturing levels of understory, litter, and soil components were also estimated. Results shown that biomass is positively correlated with carbon storage. The ecosystem carbon storage of the mixed block plantation *D.sissoo* / *T.grandis* stands (326.85 Mg ha^{-1}) was higher than those of the block plantation of *D.sissoo* (314.43 Mg ha^{-1}) and *T. grandis* (293.29 Mg ha^{-1}). The majority of carbon storage was found in the soil pool (84.71%, 63.53%, and 75.79% in the block plantation of *D. sissoo*, *T. grandis* and mixed block plantation of *D.sissoo* / *T.grandis* stands, respectively). Almost 40% of soil carbon at a depth of 0–60 cm was stored in the upper 20 cm of the soil pool. Except for the vegetation layer, each layer of the block plantation *T.grandis* and mixed block plantation *D. sissoo* / *T. grandis* stands consisted of a higher amount of carbon than did the layers of the block plantation *D.sissoo*. These findings suggest that mixed block plantation or valuable indigenous block plantation of *D. sissoo* more substantially improve carbon storage in litter, soil, and ecosystems than sole block plantation of *T. grandis*. The results also imply that developing valuable indigenous tree species is a good silvicultural option for enhancing carbon sequestration and valuable timber cultivation.

Key words: Block plantation, Carbon capturing, Carbon dioxide, Shrubs, Herbs.

Introduction

Active absorption of atmospheric CO_2 from the atmosphere through photosynthesis and its subsequent storage in the biomass of growing trees or plans is referred as carbon sequestration (Base *et al.,* 1977). The atmospheric CO_2 is utilized by the leaves fro he manufacture of food in the form of glucose, latter on, it gets converted to other forms of food materials such as starch, lignin hemi cellulose, amino acid and protein and directed to other tree component for storage. There are number of factors that influence the carbon sequestration rates of a tree *i.e.* temperature, rainfall, soil type and quality, biotic components like microbial growth, predation, pollination etc. Besides, topographical features and human disturbance are also important factors (Newaj *et al*., 2001) for carbon sequestration rates. Hence, without a greater understanding of all the above mentioned factors the biomass and carbon sequestration rates remains guesswork. To determine the role of trees in mitigating atmospheric CO_2 content, it is essential to have accurate, inventory of carbon content in trees. At present there are only few research data on carbon contents in wood of different block plantation trees. The increased demand for high-quality timber and ecological services has resulted in the cultivation of valuable indigenous broadleaved and mixed plantations (Hvistendahl, 2012).Aiming to develop multipurpose block plantation that provide good quality timber and ecological services. Some scientists have recently studied the effects of different management strategies on growth and biomass allocation patterns (Zhao *et al*., 2011). Thus far, only a few studies have examined the effects of different block plantation trees management strategies on the carbon capturing in sole block plantation trees *D.sissoo* stand and *T.grandis* stand and mixed block plantation D*. sissoo/ T.grandis* stands. The main objective of this study was to compare the potential of carbon capturing in three 20 year old block plantation and provide a management baseline for enhancing carbon sequestration and valuable timber cultivation in subtropical Gujarat. The comparison was made on the basis of similarities in topography, soil texture, stand age, and management history.

Materials and Methods

Location: Geographically, Navsari (Gujarat), India is situated at 20.95° North Latitude and 75.90° East Longitude and at an altitude of 11.98 meters from above mean sea level (MSL). The experimental site is located just 12 km away in the east from the Arabian Seashore of historical Dandi, India. It shot into worldwide prominence in 1930 when Mahatma Gandhi selected it to be the place for the Salt Satyagraha. He marched with thousands of followers on foot for 24 days from Ahmedabad, India to Dandi for protesting against the imposition of a tax on salt.

Weather and Climate: Climatically, this region is typically tropical, characterized by fairly hot summer, moderately cold winter and more humid and warm monsoon with heavy rain. The average annual precipitation is 1355 mm. Monsoon commences mostly from the second week of June and lasts up to the first week of October. Most of the rainfall is received from South West monsoon, concentrating in the months of July and August. Winter starts from the month of November with mild cold and lasts up to February. December and January are coldest months with mean monthly minimum temperature 25^0C. Summer commences from mid February and lasts up to mid June. April and May are the hottest months during which the mean monthly maximum temperature ranges from 33^0C to 35^0C. The highest mean monthly relative humidity was recorded in the month of July and ranged from 81 to 93 percent.

Soil types: The soil type of experiment site is placed under Jalalpur series, having great group chromuster, sub-order ustert and order vertisol as per seventh approximation. The clay content ranges from 42 to 50 percent, pre-dominated with montmorillonite type of clay mineral. It includes deep moderately drained clayey soils, classified as deep black soil. It is medium in fertility and has high water holding capacity (Kaswala and Despande, 1983).

Plot design: In 2012, 36 sampling plots were randomly set up with dimensions of 10 X 10 m in each of the three stands. On each plot, the diameter at breast height (DBH) of individual trees was measured with an electronic digital caliper (Mitutoyo, Japan, 0–15-cm measurement range), and the height was measured with a Haglof-VERTEX IV clinometer. Quadrants of herbaceous vegetation and litter (at 1 X 1 meach) were established diagonally within each sampling plot. Plant species, number, height, and coverage were recorded, and litter was collected from the quadrants. Environmental factors, including slope, aspect, and slope position, were also recorded.

Measurement of tree biomass: On the basis of the DBH and height measurements of the sampling plots, we selected and harvested 10 sampling trees with different diameter classes from the block plantation of *D.sissoo* stand for biomass measurement. The aboveground portions of the trees were divided into 2-cm sections for measurement according to Monsic's stratified clip method (Qin *et al.,* 2011). The fresh weights of the stems, bark, branches, and leaves were measured. The belowground portions of the sampled trees were dug out and examined using the open cut method (Qin *et al*., 2011). The fresh weights of the stump roots, thick roots (diameter >2.0 cm),medium-thick roots (diameter 0.5–2.0 cm), and fine roots (diameter <0.5 cm) were measured. The samples of these components were also collected to calculate moisture content and dry weight. The samples were then oven dried at a temperature of 80^0C to achieve a constant weight. We analyzed the measurements of the block plantation of *D.sissoo* tree components. The results of the biomass model indicate that the allometric relationship between the biomass of the tree components (W) and DBH (D) and height (H) is best fitted with the equation W= a(D_2-H)b. The coefficient of determination (R_2) ranged from 0.8102 to 0.9936. Table 2 shows that under the F-test, all the equations were extremely significant ($p< 0.01$) or significant ($p< 0.05$). The allometric equations formulated by Xia (2008) were used to estimate the biomass of the block plantation of *T.grandis* components (Table-2).

Measurement of understory vegetation and litter biomass: A destructive harvesting method was used to measure the biomass in the aboveground and belowground portions of the herbaceous layers (Qin *et al*., 2011). The fresh weights of the above ground and belowground components of the herbaceous plants were directly obtained. After oven drying weighed sub-samples to a constant weight at 80^0C, we calculated the respective dry weights by determining moisture content. The components of understory vegetation were then separated and measured. Following the measurement method designed by Kang *et al.*(2009), we measured the amount of under-decomposed and semi-decomposed materials in the litter once a month from January to December 2012. The litter samples were oven dried at 80^0C and weighed.

Measurement of carbon content: Samples of the aboveground and belowground components of the trees (*D.sissoo*), herbaceous plants, and litter, were dried, smashed, and sifted in the laboratory. These were then bottled for chemical analysis. A total of 27 soil-sampling points were selected along the upper (9 samples), middle (9 samples), and lower (9 samples) slopes within the 36 sampling plots in each of the three stands. Soil pits were dug to a depth of 60 cm and samples were collected from three depth levels: 0–20 cm, 20–40 cm, and 40–60 cm. Soil samples from the same depth layer in the same stand were mixed in equal proportions and the mixtures were air dried at room temperature (25^0C). The mixtures were then smashed and passed through a 2-mm mesh sieve to remove coarse living roots and gravel, and then ground with a mill for passing through a 0.25-mm mesh sieve before chemical analysis. A soil sample ring kit (100 cm^3) was used to collect samples of undisturbed soil at different layers. These samples were taken to the laboratory for measurements of soil bulk density by the cutting ring method. The carbon content of the *D.sissoo* components was determined from the sampled trees, whereas that of the *T.grandis* components was determined from the data collected by Xia (2008) (Table 3). These data can be used to estimate tree carbon storage on the basis of total tree biomass. The carbon contents in the vegetation, litter, and soil samples were measured by the dichromate oxidation method (Nelson and Sommers, 1996).

Measurement of carbon storage: We determined the carbon storage (i.e., carbon in biomass per unit of land) in the vegetation and litter biomass by multiplying carbon content with biomass amount (dry weight per unit of land). We calculated the carbon storage in the different layers of soil by multiplying soil bulk density with soil depth and the carbon content in each layer of soil (per unit of land), and computed the total carbon capturing in soil by summing the carbon capturing in each layer of soil.

Statistical analysis: To assess the differences in carbon content and carbon capturing among the different components of the block plantation ecosystems, we analyzed the results using one-way ANOVA. All analyses were performed using Microsoft Excel 2007 and SPSS 17.0 for Windows. Statistical significance was set at $p< 0.05$ or 0.01.

Results

Carbon content in Understory vegetation and litter layer: The average carbon of the shrubs in the *D.sissoo* stand (453.86 g kg^{-1}) was less than those in the *T. grandis* (473.56 g kg^{-1}) and mixed *D.sissoo/ T. grandis* (461.65 g kg^{-1}) stand, but the difference was non-significant ($p>0.05$). The mean carbon contents of the herbaceous layer in the *D.sissoo* and mixed *D.sissoo/ T. grandis* stand were almost the same ($p>0.05$), but both values were significantly lower than that of the *T. grandis* stand ($p< 0.05$) (Table 4). In all the three block plantation stands, the carbon contents of the aboveground components of the shrubs and herbs were higher than those of the belowground components; only the difference in carbon contents of the herbs in the *T. grandis* stand was significant ($p< 0.05$) (Table-4). The mean carbon content of the litter layer was significantly lower in the *D.sissoo* stand (424.59 g kg^{-1}) than in the *T. grandis* (505.14 g kg^{-1}) and mixed *D.sissoo/ T. Grandis* stand (526.96 g kg^{-1}) stands ($p<0.05$).

Soil layer: The carbon contents of the soil layers decreased as depth increased (Table-4). The carbon content of the topsoil (0–20-cm depth) was more than 1.9 times over that of the substrate (40–60-cm depth). The mean carbon contents of the top soil and entire soil layers of the *D.sissoo* and mixed block plantation *D.sissoo/ T. grandis* stand were significantly greater than that of the soil layers in the *T. grandis* ($p<0.05$).

Carbon storage and spatial allocation in vegetation layer: Table-5 shows that the carbon storage levels in all the vegetation layers, i.e., the trees, shrubs and herbaceous plants of the *D.sissoo*, *T. grandis* and mixed *D.sissoo/ T. grandis* stand, were 46.73, 106.44, and 78.10 Mg ha^{-1}, respectively. Of these levels, >99% and <1% are attributed to trees and shrubs and herbaceous plants, respectively. Among the tree components, stems had the highest carbon capturing at 63.84% in the *D.sissoo* stand, 49.14% in the *T. grandis* and 56.83% in the mixed plantation *D.sissoo/ T. grandis* stands (Table-5).

Litter and soil layer: Table-5 also shows that the carbon storage in litter was greater in the *D.sissoo* (1.31 Mg ha^{-1}) and mixed block plantation *D.sissoo/ T. grandis* stands (1.05 Mg ha^{-1}) than in the *T. grandis* (0.60 Mg ha^{-1}). The total carbon capturing in the soil was greatest in the *D.sissoo* stand at 266.55 Mg ha^{-1}; those stored in the mixed block plantation *D.sissoo/ T. grandis* stands and *T. grandis* were 247.88 and 186.56 Mg ha^{-1}, respectively. In the three stands, the carbon capturing in the soil layers decreased as depth increased,

Table-1: Stand characteristics and soil physical properties of the experiment

Stand characteristics/ properties	*D. sissoo stand*	*T. grandis stand*	Mixed *D. sissoo/ T. grandis stand*
Slope aspect	South	Southwest	South
Slope gradient (%)	30	31	35
Sand (%)	62	57	59
Silt (%)	7	8	7
Clay (%)	31	35	34
Main understory vegetation (Shrubs)	*Calotropis procera, Dodonaia viscosa, Cassia auriculata*	*Calotropis procera, Dodonaia viscosa, Cassia auriculata*	*Calotropis procera, Dodonaia viscosa, Cassia auriculata*
(Herbaceous plants)	*Saccharum spontaneum, Panicum antidotale*	*Saccharum spontaneum, Panicum antidotale*	*Saccharum spontaneum, Panicum antidotale*
DBH (cm)	24.50±1.75	24.27±1.98	27.15±0.96
Tree Height (m)	19.40±0.42	18.53±0.80	20.00±0.72
Stem density (trees ha^{-1})	450	442	410

Table-2 : Allometric equations used to calculate the biomass of the various tree components

Component	*D. sissoo stand*			*T. grandis stand*	
	Allometric equation	Correlation coefficient (*R*)	*F* value	Allometric equation	Correlation coefficient (*R*)
Stem	$Ws=0.06411 (D^2H)^{0.8699}$	0.9968	462.287**	$WS = 0.017470(D^2H)^{0.998299}$	0.995567
Bark	$WBA=0.01050(D^2H)^{0.8246}$	0.9606	47.767**	$WBA = 0.004736(D^2H)^{0.876541}$	0.934976
Branches	$WBR = 0.00011(D^2H)^{1.3949}$	0.9001	17.070*	$WBR = 0.000030(D^2H)^{1.571689}$	0.989238
Leaves	$WL = 0.0000028(D^2H)^{1.6052}$	0.9523	38.961**	$WL = 0.000254(D^2H)^{1.261464}$	0.960052
Roots	$WR = 0.12098(D^2H)^{0.6495}$	0.9022	17.507*	$WR = 0.001510(D^2H)^{1.160023}$	0.991597

* Present difference at level of $p < 0.05$; ** Present difference at level of $p < 0.01$.

Table-3: Carbon content of sole stand in *D. sissoo* and *T. grandis*

Tree species	Stem (g kg^{-1})	Bark(g kg^{-1})	Branch (g kg^{-1})	Leaves (g kg^{-1})	Roots (g kg^{-1})	Mean (g kg^{-1})
D. sissoo	523.40±14.02	543.42±26.43	506.11±27.00	524.18±15.55	451.24±16.83	509.67±19.97
T. grandis	502.29±22.23	503.78±28.92	513.75±33.51	552.46±28.95	473.84±35.74	509.22±29.87

Various small letters in a row are a significantly different level ($P < 0.05$), various capital letters in a column are a significantly different level ($p < 0.05$).

Table-4 : Carbon content in understory vegetation, litter and soil layers

Layer	Component	*D. sissoo stand*	*T. grandis stand*	Mixed *D. sissoo/ T. grandis stand*
Shrubs	Above-ground	495.62 ± 12.72a	519.71 ± 17.37a	484.79 ± 24.42a
	Belowground	412.09 ± 50.82a	427.41 ± 17.51a	438.51 ± 17.37a
	Mean	453.86 ± 31.77a	473.56 ± 17.44a	461.65 ± 20.89a
Herbaceous plants	Above-ground	464.11 ± 13.45a	536.61 ± 16.04b	491.16 ± 23.24a
	Belowground	359.45 ± 27.68a	408.04 ± 59.38a	344.14 ± 39.99a
	Mean	411.78 ± 20.57a	472.32 ± 37.71b	417.65 ± 31.61a
Litter		424.59 ± 19.51a	505.14 ± 35.59b	526.96 ± 7.73b
Soil	0-20 cm	39.72 ± 6.58a	24.93 ± 2.35b	37.67 ± 7.73a
	20-40cm	23.33 ± 1.58a	21.54 ± 5.16a	26.28 ± 4.31a
	40-60cm	18.78 ± 3.36a	13.01 ± 3.35a	18.98 ± 2.80a
	Mean	27.28 ± 3.84a	19.83 ± 3.62b	27.64 ± 4.95a

Different letters in the same row means different levels of significance ($P < 0.05$).

Table 5 : Biomass, carbon capturing and spatial allocation in plantation stand

Layer	Component	*D. sissoo stand*		*T. grandis stand*		Mixed *D. sissoo/ T. grandis stand*	
		Biomass ($Mg\ ha^{-1}$)	Carbon storage ($Mg\ ha^{-1}$)	Biomass ($Mg\ ha^{-1}$)	Carbon storage ($Mg\ ha^{-1}$)	Biomass ($Mg\ ha^{-1}$)	Carbon storage ($Mg\ ha^{-1}$)
Trees	Stem	56.62 ± 28.89A	29.63 ± 15.12a	103.59 ± 5.42B	52.03 ± 2.72a	85.11 ± 10.81AB	43.97 ± 5.57a
	Bark	6.22 ± 3.08A	3.38 ± 1.67a	8.81 ± 0.51A	4.44 ± 0.26a	8.47 ± 1.02A	4.50 ± 0.51a
	Branches	10.70 ± 7.15A	5.41 ± 3.62a	41.98 ± 3.12B	21.57 ± 1.60b	27.94 ± 3.76C	14.20 ± 1.84c
	Leaves	1.82 ± 1.32A	0.95 ± 0.69a	18.48 ± 1.00B	10.21 ± 0.55b	8.43 ± 1.31C	4.54 ± 4.06c
	Roots	15.60 ± 6.84A	7.04 ± 3.09a	37.23 ± 9.30B	17.64 ± 4.41b	22.00 ± 3.57AB	10.16 ± 1.76ab
	Subtotal	90.96 ± 47.27A	46.41 ± 24.19a	210.09 ± 16.79B	105.89 ± 8.24b	151.95 ± 20.08A	77.37 ± 8.03a
Shrubs	Aboveground	0.18 ± 0.02A	0.09 ± 0.01a	0.35 ± 0.26A	0.18 ± 0.14a	0.20 ± 0.02A	0.10 ± 0.02a
	Belowground	0.17 ± 0.02A	0.07 ± 0.01a	0.31 ± 0.18A	0.13 ± 0.08a	0.19 ± 0.03A	0.08 ± 0.02a
	Subtotal	0.35 ± 0.03A	0.16 ± 0.02a	0.66 ± 0.44A	0.31 ± 0.22a	0.39 ± 0.05A	0.18 ± 0.03a
Herbaceousplants	Aboveground	0.20 ± 0.01A	0.09 ± 0.01a	0.26 ± 0.14A	0.14 ± 0.08a	0.62 ± 0.33A	0.31 ± 0.15a
	Belowground	0.20 ± 0.01A	0.07 ± 0.01a	0.25 ± 0.13A	0.10 ± 0.04a	0.69 ± 0.02B	0.24 ± 0.02b
	Subtotal	0.40 ± 0.01A	0.16 ± 0.02a	0.51 ± 0.27AB	0.24 ± 0.12ab	1.31 ± 0.32B	0.55 ± 0.15b
Litter		3.09 ± 0.93A	1.31 ± 0.41a	1.19 ± 0.11B	0.60 ± 0.08b	1.99 ± 0.63AB	1.05 ± 0.34ab
Soil	0–20 cm		124.59 ± 20.76a		73.23 ± 6.28b		102.12±16.77a
	20–40 cm		77.90 ± 5.53a		67.41 ± 18.64a		84.12±15.00a
	40–60 cm		64.06 ± 11.19a		45.92 ± 10.52a		61.64±11.74a
	Subtotal		266.55 ± 35.96a		186.56 ± 34.26b		247.88±37.42a
Total		94.80 ± 46.78A	314.59 ± 49.67a	212.45 ± 17.80B	293.60 ± 34.81a	155.64 ± 21.01A	327.03±44.70a

Different letters in the same row for biomass (capital letter) and carbon storage (small letter) mean different levels of significance ($P < 0.05$).

which is consistent with the distribution of carbon content in the soil. The topsoil layer capturing the most carbon. In the three stands, 39.25–46.74% of the total carbon capturing in the soil occurred at a depth of 0–20 cm.

Plantation ecosystem: As shown in Table-5, the total carbon storage levels in the *D.sissoo*, *T. grandis* and mixed *D.sissoo/T. grandis* stand were 314.59, 293.60, and 327.03 Mg ha^{-1}, respectively. This result indicates that carbon storage is ranked in the order soil > vegetation > litter. The trees in the three stands accounted for total carbon storage levels of 14.75%, 36.07%, and 23.66% in the *D.sissoo*, *T. grandis* and mixed *D.sissoo/T. grandis* stand, respectively. The shrubs and herbaceous plants accounted for 0.10%,0.19%, and 0.22%; litter accounted for 0.42%, 0.20%, and 0.32%; and soil accounted for 84.73%, 63.54%, and 75.80%, respectively.

Discussion

Carbon content in vegetation layer: Carbon content in block plantation stand ecosystems can vary with plantation type, species composition, and site conditions, and is positively correlates with carbon storage (Kang *et al.*, 2006). The mean carbon content of *D.sissoo* (509.67 g kg^{-1}) is similar to that of *T. grandis* (509.22 g kg^{-1}) (Table-3). The variations in the mean carbon content of the herbaceous plants ranged from 411.78 g kg^{-1} to 472.32 g kg^{-1} (Table 4). These results are consistent with previous studies (Zhao *et al.*, 2011), and show that the carbon contents of the various vegetation layers in the same stand are ranked in the order trees >shrubs> herbaceous plants (Tables-3 and 4); this ranking is attributed to the fact that trees can synthesize and accumulate more organic matter, thereby resulting in more carbon content than that found in understory components.

Litter layer: The carbon content of litter depends on many factors, such as litter type, decomposition rate, micro-environment, and litter productivity (Zhou *et al*., 2000). Some studies revealed that litter decomposes at a considerably faster rate in broadleaved forests than in coniferous forest, resulting in less carbon content in the former than in the latter (Huang *et al*., 2010). In the current study, the mean carbon contents of litter were 526.96 g kg^{-1} in the mixed block plantation stands, 505.96 g kg^{-1} in the *T. grandis* and 424.59 g kg^{-1} in the *D.sissoo* stand, consistent with the aforementioned studies.

Soil layer: The mean carbon contents of the soil layers in each stand decreased as soil depth increased, and were significantly higher in the *D.sissoo* and mixed block plantation *D. sissoo* / *T. grandis* stands than in the *T. grandis* ($p < 0.05$).These results may be attributed to the faster decomposition of litter carbon in the soil of the *D.sissoo* and mixed block plantation. The carbon content in the topsoil (0–20-cm depth) was higher than that in the substrate (40–60-cm depth) because the organic carbon produced from the decomposition of the litter and root systems near the ground surface enters the topsoil first (Tian *et al*., 2010).

Carbon storage in vegetation and litter layer: Estimating the carbon stock pools capturing in various block plantation stands can facilitate decision making on carbon management. Carbon storage depends on species-specific wood density, biomass, carbon content, and therefore, the planting densities and structures of plantation stands. In this study, biomass was found positively correlated with carbon storage (Table-5). The tree carbon storage levels in the mixed block plantation *D.sissoo/ T. grandis* stands and *D.sissoo* stand were significantly lower than that in the *T. grandis* ($p < 0.05$). Such difference in storage levels may have occurred because the *T. grandis* had the highest stem, branch and root biomass, and the *D.sissoo* had the least tree biomass (Table-5). The carbon capturing in the understory vegetation of the mixed block plantation *D.sissoo/ T. grandis* stands was 32.73% higher than that of the *T. grandis* and 128.13% higher than that of the *D.sissoo*. This result stemmed primarily from the more abundant herbaceous plant biomass in the mixed block plantation stands than in the *T. grandis* and *D.sissoo* stands (Table-5). The carbon capturing in litter was higher in the *D.sissoo* than that in the *T. grandis* ($p<0.05$) and mixed block plantation *D.sissoo* /*T. grandis* stands ($p>0.05$) resulted from the higher amount of litter biomass in the broadleaved stand than in the mixed broadleaved and sole block plantation species (Zheng *et al.,* 2005).

Soil layer: The soil was the main carbon pool for the three plantations. Some factors, such as litter, root turnover, and soil chemistry, can alter soil organic carbon stock (Jandl *et al*., 2007; Wang *et al.* 2013). In this study, the carbon capturing was significantly higher in the soil (0–60-cm depth) of the *D.sissoo* and mixed block plantation *D.sissoo* / *T. grandis* stands than that in the *T. grandis* ($p < 0.05$). It is also higher than the average carbon storage in soils in south Gujarat (193.55 Mg ha^{-1}) (Zhou *et al.,* 2000) because the litter of *D.sissoo* more easily decomposes, adding to the input of soil carbon in the *D.sissoo* and mixed block plantation *D.sissoo*// *T. grandis* stands, thus the enhanced accumulation of organic carbon in the soil. In the three stands, soil carbon storage was highest at a depth of 0–20 cm (accounting for 39.25–46.74%). This storage level decreased as soil depth increased. Because soil organic matter is the main source of the carbon stored in topsoil and because it is essential to ecosystem productivity and regeneration, the negative impacts of human disturbance (e.g., damage to understory vegetation and litter caused by agroforestry management activities) on experimental soil should be minimized or avoided, and the measurements for the maintenance of soil organic matter should be integrated into soil management strategies (Seely *et al.,* 2010).

Plantation ecosystem: Ecosystem carbon storage was higher in the mixed block plantation *D.sissoo*/*T. grandis* stands (327.03 Mg ha^{-1}) than in the *D.sissoo* (314.59 Mg ha^{-1}) and *T. grandis* (293.60 Mg ha^{-1}) stands, but the difference was non-significant ($p>0.05$). The aboveground biomass carbon (stems, bark, branches, leaves, herbs, and litter) and belowground soil carbon were the major components of ecosystem carbon stock and the major reason for the differences in the ecosystem carbon stock among the three plantation stands. The highest aboveground biomass carbon was observed in the *T. grandis* (89.17 Mg ha^{-1}), followed by the mixed block plantation stands (68.67 Mg ha^{-1}) and *D.sissoo* (40.86 Mg ha^{-1}) stands. This result is attributed to the *T. grandis* stand having the largest tree biomass. The belowground soil carbon constituted the largest carbon pool in the three plantation stands, accounting for 84.73%, 63.54%, and 75.80% in the *D.sissoo*, *T. grandis*, and mixed block plantation *D.sissoo* /*T. grandis* stands, respectively. This finding is similar to those of previous studies (Tandel *et al*., 2009; Tian *et al.,* 2010; Wang *et al*., 2013).

Carbon content is one of main factors used to determine the carbon capturing in plantation stands, it is affected by block plantation type, species composition, and site conditions. In this study, the trees and shrubs in the three plantation stands exhibited a non-significant ($p>0.05$) difference in carbon content, whereas the herbaceous plants in the mixed block plantation *D.sissoo/ T. grandis* and *D.sissoo* stands showed significantly lower carbon contents than that did the herbaceous plants in the *T. grandis* stands ($p<0.05$). With regard to litter, the soil carbon content was significantly higher in the mixed block plantation stands and *T. grandis* than in the *D.sissoo* stand ($P<0.05$). The carbon capturing in vegetation follows the rank *T. grandis* > mixed block plantation *D.sissoo /T. grandis* stands > *D.sissoo* stands. The carbon storage in litter and soil follows the rank *D.sissoo* > mixed block plantation *D.sissoo*/*T. grandis* stands > *T. grandis* stands. Soil was the greatest carbon pool, accounting for 84.73%, 63.54%, and 75.80% in the *D.sissoo*, *T. grandis*, and mixed block plantation *D.sissoo* /*T. grandis* stands, respectively. Almost 40% of the soil carbon at a depth of 0–60 cm was stored in the upper 20 cm. Therefore, measures for minimizing or avoiding soil surface disturbance should be incorporated in block plantation management practices. The carbon capturing in the plantation ecosystems presented in the order mixed block plantation *D.sissoo*/*T. grandis* stands > *D.sissoo* > *T. grandis*. These findings suggest that mixed block plantation *D.sissoo* /*T. grandis* stands or valuable indigenous *D.sissoo* plantations stand more substantially improves the carbon storage in litter, soil, and ecosystems than do sole plantation *T. grandis* stands in tropical Gujarat. We also highlight the need to monitor and assess the long-term changes in stand structure, biomass production and carbon stock in the three plantations.

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