Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2017, Volume 8, Issue 12, Page 4565-4572

http://www.jmaterenvironsci.com

Vegetation and Soil Carbon Pools of Mixed Plantation of *Acacia nilotica* and *Dalbergia sissoo* under Social Forestry Scheme in Kurukshetra, India

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Received 18 Jan 2017,
Revised 31 Aug 2017,
Accepted 2 Sep 2017

Keywords
- *Acacia nilotica;*
- *Dalbergia sissoo;*
- *Carbon pool;*
- *Carbon sequestration;*
- *Biomass;*
- *Soil organic carbon;*
- *Soil respiration;*
- *Litterfall;*

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Abstract
Tree plantations can serve as an important tool in regulating the climate by sequestering the excess amount of atmospheric carbon dioxide in biomass and soil pools. A mixed plantation of *Acacia nilotica* and *Dalbergia sissoo* planted under social forestry scheme of Forest Department of Haryana in campus of Kurukshetra University, Kurukshetra (Haryana) was assessed for its carbon sequestration potential. The above ground and below ground carbon pool as a fraction of biomass was calculated as 32.87 $Mgha^{-1}$ and 8.57 $Mgha^{-1}$, respectively. The carbon flux through net primary productivity and CO_2 assimilation rate of the plantation was 2.27 $Mgha^{-1}yr^{-1}$ and 8.33 $Mgha^{-1}yr^{-1}$ respectively. The total carbon stock in soil up to one meter soil depth was estimated to be 111.71 $Mgha^{-1}$ comprising 95.98 $Mgha^{-1}$ as organic and 15.73 $Mgha^{-1}$ as inorganic carbon stock. The microaggregates (250µm-53µm) formed a large fraction of soil aggregates and protected most of soil organic carbon in the soil. The annual loss of carbon as soil respiration from the surface soil was 9.99 $Mgha^{-1}$. The rates of CO_2 evolutions from the soil surface were found to be positively and significantly correlated with soil moisture ($r= 0.809$; $p<0.001$), soil temperature ($r=0.65$; $p<0.05$), atmospheric temperature ($r=0.676$; $p<0.05$). This study demonstrated that tree plantations with such large storage houses of carbon in their vegetation and soil can play a significant role in mitigating the dire consequences of climate change by decreasing or stabilizing the concentrations of atmospheric carbon dioxide and hence should be promoted for various land uses

1. Introduction
Climate change is one of the primary concerns of humanity today. Changes have occurred in the composition of greenhouse gases over the long time scales of glacial and interglacial periods. In 2011 the concentrations of carbon dioxide in the atmosphere was estimated to be 391 ppm, which has exceeded the pre-industrial levels by about 40% [1]. Climate change mitigation requires the management of terrestrial carbon (C) either by creating new C sinks or by preserving existing ones. Carbon sequestration is one such option that can occur in living biomass, in soil (roots and microbes) and recalcitrant organic and inorganic carbon in soil. With numerous additional benefits such as improved soil and water quality, restoration of degraded ecosystem, increased crop yield etc., tree carbon sequestration often proves to be a win-win strategy. Therefore, growing trees in proper land use pattern can be a potential contributor in reducing the concentration of CO_2 in atmosphere by its accumulation in the form of biomass [2].
Forests have a vital role to play in the fight against global warming. Tropical forests dominate the role of forests in the global carbon flux and stocks, and therefore require researchers and policy makers to estimate their potential to sequester carbon [3]. Trees in the forest (including plantations), in general sequester carbon at a maximum rate between the age of 10-30 years [4]. The major aspects affecting the potential of tree plantations in carbon sequestration are soil organic and inorganic carbon pools, rates of CO_2 evolution from the soil surface, carbon sequestration in tree biomass and carbon fluxes through net primary productivity. The scheme of 'social forestry' was first introduced by National Commission on Agriculture, Government of India in 1976. Since then enormous afforestation programme have been undertaken by Forest Department, Haryana, on various

Government Lands, Institutional Lands, Panchayat Lands, Common Lands and other waste lands to increase the forest and tree cover [5]. The recorded forest area of the state of Haryana is only 3.59% of its total geographical area out of which reserved forests constitute 15.97%, protected forest 74.28% and 9.75% is covered by unclassed forests [6]. Hence, Social forestry schemes have potential to make considerable differences in overall forest cover in a short time and also carbon sequestration by trees could provide relatively low-cost net emission reductions. Therefore, the objectives of the present study were to (i) vegetation carbon pools through Net Primary Production; (ii) soil carbon pools; (iii) carbon storage in soil aggregates and (iv) CO_2 evolution rate from soil of the mixed plantation of *Acacia nilotica* and *Dalbergia sissoo.*

Study Site

The study site was located on the campus of Kurukshetra University, Kurukshetra. The district of Kurukshetra with an area 1682.53 Sq.Kms, lies between latitude 29°-52' to 30°-12' and longitude 76°-26' to 77°-04' in the North Eastern part of Haryana State. The mixed plantation of *Acacia nilotica* and *Dalbergia sissoo* was done in year 2001 by Forest Department of Haryana, under Social Forestry Scheme. The tree density was 765/ha and the distance between the rows of trees and between trees in a row was 6.0 m and 3.5 m, respectively. The climate of the District is characterized by very hot summers (up to 45ºC) and very cold winters (about 3ºC). The maximum and minimum temperature ranged from 18.77 to 45.15ºC and 5.37 to 32.15ºC, respectively from January, 2012 to December, 2012. The mean monthly maximum and minimum temperature and rainfall for the year 2012 (Indian Meteorological Department) is given in Figure 1.

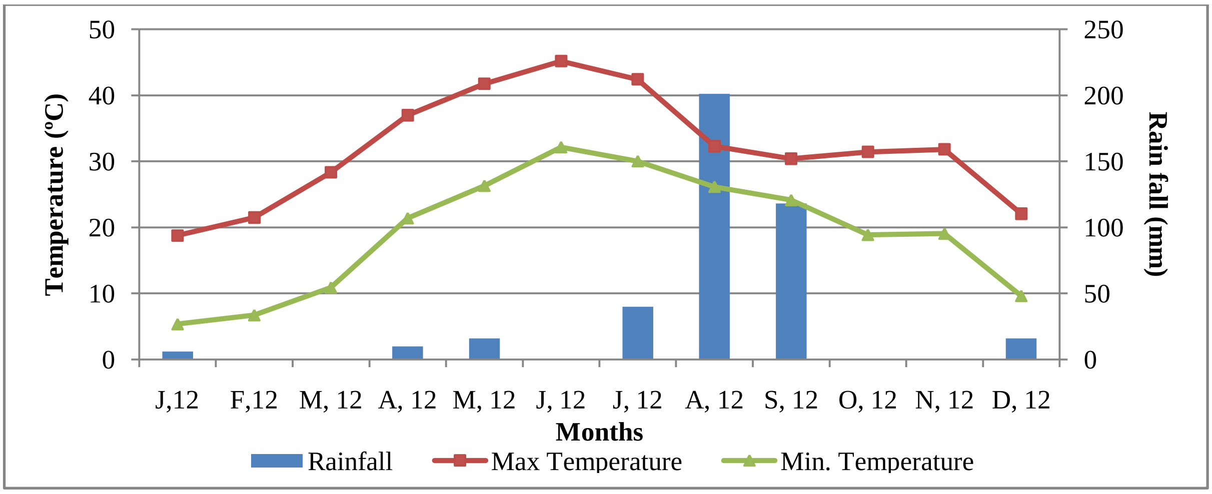

Figure 1: Climatograph of the study area from January, 2012 to December, 2012

The entire district of Kurukshetra is covered by tropical arid brown soils which are mildly alkaline to strongly alkaline in reaction and medium to high in organic matter. The soil type of study area was of clay loam texture.

2. Experimental Details

2.1 Estimation of Plant Biomass, Net Primary Productivity and Carbon Pool

The experimental plots (20 x 20 m) were demarcated within the mixed plantation. Component wise (above and below ground) biomass of trees was estimated by dimension analysis of sample trees based on diameter at breast height (dbh) using linear regression equations developed by Singh and Toky [7] for *Acacia nilotica* and by Lodhiyal and Lodhiyal [8] for *Dalbergia sissoo*. Total Net Primary Productivity was estimated as the sum of increment in biomass of tree components (above ground and below ground) over a period of one year. Carbon pool of various tree components was calculated by multiplying factor (0.475) with the estimated biomass values. Estimated C stocks in tree components were converted to CO_2 equivalents (C x 3.67) for calculating CO_2 assimilation by biomass. Litter production was estimated on the basis of 15 randomly placed 1 x 1 m litter traps. Litter was collected at monthly intervals. Samples were sorted into leaf litter and twig litter and weighed after oven drying at 60 ºC. Monthly estimates were summed up to get annual litter production.

2.2 Soil Sampling and Analysis

The soil samples were collected down to one meter depth (0-15cm, 15-30cm, 30-45cm, 45-60cm and 60-100cm) using soil corer. Some samples were procured for measurement of bulk density and moisture content and others were air dried, ground and stored for further chemical analysis. Soil moisture was determined using a moisture meter (IR 60, Denver Instruments) and bulk density by soil core method. Soil pH was measured in 1:2 ratio with distilled water using Systronics µpH System 361. Soil aggregates were determined by wet sieve method [9]. Total carbon (%) in soil was determined following dry combustion method through CHNS analyzer (ElementR Vario Macro). Organic carbon (%) in soil samples and soil aggregates was analyzed by wet digestion method [10]. Soil Inorganic carbon (%) was determined as the difference between total soil carbon and soil organic carbon [11]. Soil Carbon stocks were estimated from bulk density, soil depth, and organic carbon concentration in soil of the respective soil depth. CO_2 evolution rate of soil (soil respiration: Mg CO_2-C/ha/day) of different plantations was measured in situ by alkali absorption method [12].

2.3 Statistical analysis

The results of the study were analyzed statistically through correlation analysis between soil respiration rates and soil parameters and atmospheric parameters. The differences in soil parameters were analyzed through two-way ANOVA using MS Excel spreadsheets.

3. Results and Discussion

3.1 Plant biomass, carbon pool and CO_2 assimilation rate of the mixed plantation of A. nilotica and *D. sissoo*

The quantity of biomass in a forest is the result of the difference between production through photosynthesis and consumption by respiration and harvest processes. Thus it is a useful measure for assessing changes in forest structure [13]. The mixed plantation of *A. nilotica* and *D. sissoo* had a basal area of 64.59 m^2/ha in 2011 which increased to 69.88 m^2/ha in 2012. The total above ground biomass estimated for this plantation was 65.41 Mg/ha in 2011 and 69.19 Mg/ha in the next year indicating above ground net primary productivity of 3.78 Mg/ha/yr. Below ground component accounted for NPP of 1.00 Mg/ha/yr with 17.05 Mg/ha biomass in 2011 and 18.05 Mg/ha biomass in 2012. The total biomass (AGB and BGB) for the plantation was thus estimated to be 82.46 Mg/ha in 2011 and 87.24 Mg/ha in 2012 with Net Primary Productivity of 4.78 Mg/ha/yr. The corresponding total carbon pool (AG+BG) of the plantation was 39.17Mg/ha in 2011 which increased to 41.44 Mg/ha indicating carbon flux of 2.27 Mg/ha. The CO_2 assimilation rate of the plantation was estimated to be 8.33Mg/ha/yr from both above and below ground components (Table 1).

Table 1: Biomass, carbon pool and CO_2 assimilation rate of the mixed plantation of *A. nilotica+D. sissoo*

	Biomass (Mg/ha)		
	2011	**2012**	**NPP (Mg/ha/yr)**
AG	65.41	69.19	3.78
BG	17.05	18.05	1.00
TOTAL	**82.46**	**87.24**	4.78
	Carbon Pool (Mg/ha)		
	2011	**2012**	**Carbon Flux (Mg/ha/yr)**
AG	31.07	32.87	1.80
BG	8.10	8.57	0.47
TOTAL	**39.17**	**41.44**	2.27
	CO_2 Assimilation (Mg/ha)		
	2011	**2012**	**Assimilation Rate (Mg/ha/yr)**
AG	114.03	120.62	6.59
BG	29.72	31.47	1.74
TOTAL	**143.75**	**152.08**	**8.33**

3.2 Monthly variations in litter fall from Acacia nilotica and *Dalbergia sissoo plantation*

The total litter fall of *A. nilotica* and *D. sissoo* plantation ranged from 139.24-600.46Kg/ha over the study period of twelve months from January 2012 to December 2012. The leaf litter ranged from 109.46-512.98Kg/ha and wood litter ranged from 29.78-87.48Kg/ha. Most of the litter fall was concentrated in the months of November to March being maximum in the month of December. The amount of litter was observed to be minimum in the month of August. The contribution of leaf litter to the total litter was 80% and that of wood litter was 20% (Figure 2).

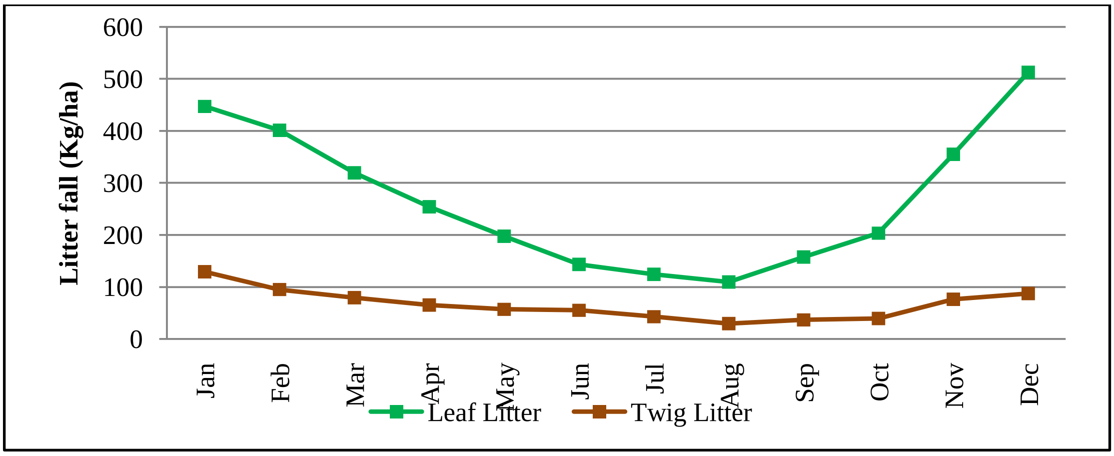

Figure 2: Monthly variations in litter fall in *A. niltoica* and *D. sissoo* plantation

3.3 Physico-chemical properties of soil

Soil samples collected were analyzed for the physio-chemical properties comprising moisture content, pH, bulk density, soil total carbon content (STC), soil organic carbon content (SOC) and soil inorganic carbon (SIC) content. The moisture content, pH and bulk density in general increased down the depth. The moisture content ranged from 9.47 to 13.48%, pH ranged from 6.05 to 7.01 and bulk density ranged from 1.06 to 1.35g/cm^3 down to one-meter depth. Soil total carbon and soil organic carbon content decreased down the depth while an increasing trend was observed in soil inorganic carbon content (Table 2).

Table 2: Physico-chemical properties of soil in the mixed plantation of *A. nilotica* and *D. sissoo*

Soil Depth (cm)	Moisture Content (%)	pH	Bulk Density (g/cm^3)	STC (%)	SOC (%)	SIC (%)
0-15	9.47±0.50	6.05±0.03	1.06	1.773	1.751	0.022
15-30	10.52±0.28	6.33±0.03	1.13	1.291	1.260	0.031
30-45	11.63±0.39	6.63±0.03	1.20	0.835	0.724	0.111
45-60	12.21±0.44	6.81±0.02	1.28	0.785	0.644	0.141
60-100	13.48±0.51	7.01±0.02	1.35	0.584	0.396	0.188

The total carbon stocks (STC) and organic carbon stocks (SOC) of soil in the mixed plantation generally declined with increasing depth. However, in the 60-100 cm depths, the total stocks were higher than the upper layers (due to larger depth size of 40cm sampled) though the percentage of carbon was lower at that depth. The inorganic carbon stocks (SIC) of the soil generally increased down the depth. The total STC stocks of the plantation were estimated to be 111.71 Mg/ha, total SOC stocks 95.98 Mg/ha and total soil inorganic carbon stocks were 15.73 Mg/ha up to one-meter depth (Figure 3a, b, c).

Soil aggregates are the basic unit of soil structure influencing many physical and biological processes of the soil. The aggregate size fractions in the soil from different soil depths are given in Table 3. The maximum contribution in weight was observed to be from the micro-aggregates (250µm-53µm) followed by silt and clay associated fraction (<53µm) and macro-aggregates (2mm-250µm) at all the depths. The percent weight contribution from macro-aggregate size class was 11-20% and from micro-aggregates was 57-68% in all depths. The silt and clay associated fraction contributed 19-23% weight to the whole soil. The differences in percent weight distribution among the three classes were observed to be significant (ANOVA $p<0.05$, 0.01) but not significant between different depths.

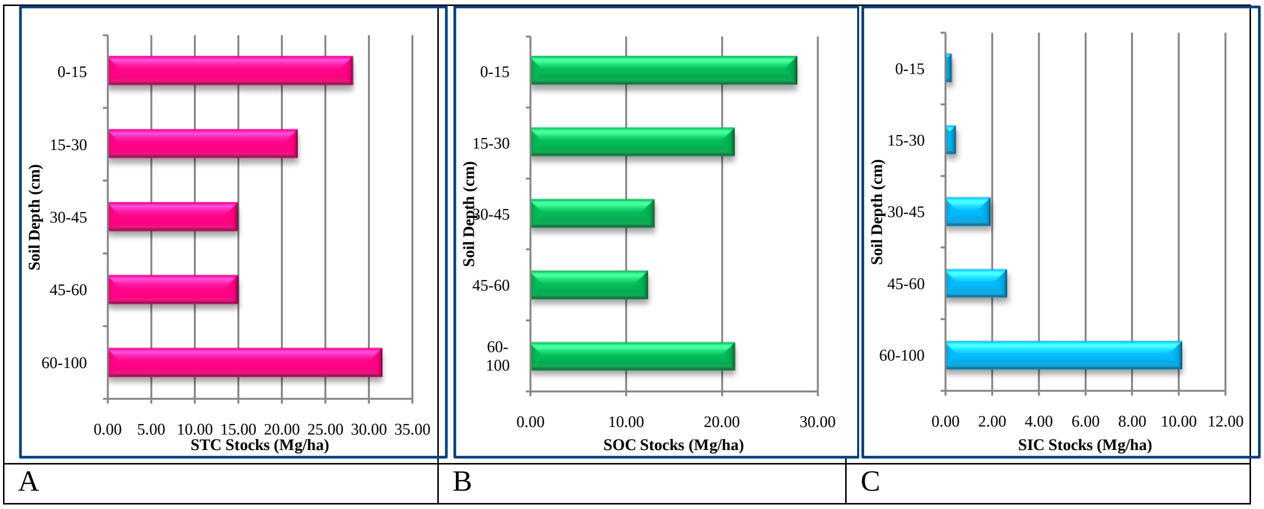

Figure 3: (a) Soil Total Carbon stocks; **(b)** Soil Organic Carbon Stocks and **(c)** Soil Inorganic Carbon Stocks in the mixed plantation of *A. nilotica* and *D. sissoo*

Table 3: Soil weight (%) distribution in aggregate size classes at different depths in *A. nilotica+D. sissoo* plantation

Soil Depth (cm)	2mm-250µm	250µm-53µm	<53µm
0-15	14.24±0.78	60.18±1.12	21.99±0.29
15-30	19.72±0.34	57.33±0.68	21.17±0.73
30-45	13.22±0.67	64.11±0.39	20.60±0.64
45-60	11.39±0.30	67.76±0.54	18.84±0.32
60-100	14.08±0.48	56.62±0.70	23.28±0.18

The nature of soil aggregation, and land use and land cover management [14-16] determines the scope of C retention in soils. The carbon content in the soil samples of study site was maximum in macro-aggregates (2mm-250µm), followed by micro-aggregates (250µm-53µm) and silt and clay associated soil fraction (<53µm) along all depths (Figure 4).

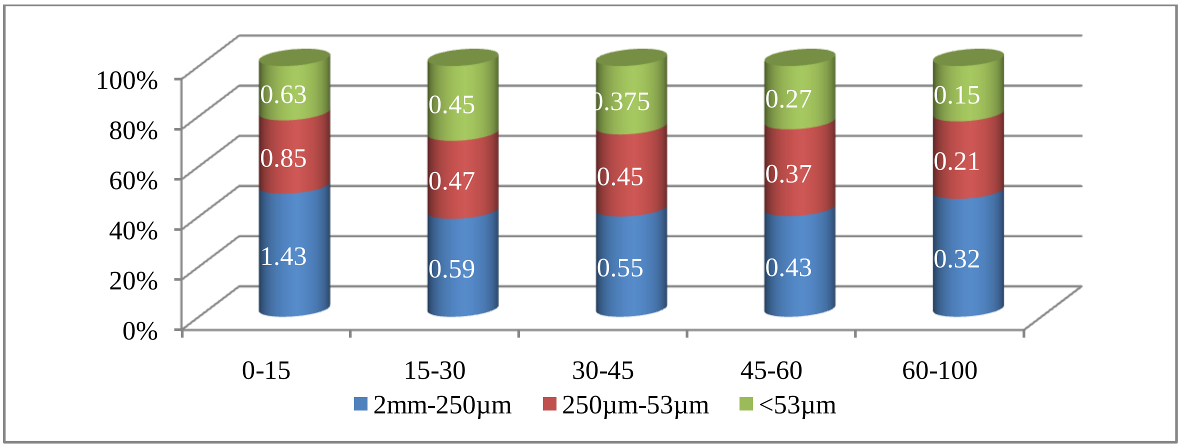

Figure 4: Organic carbon (%) distribution in aggregate size classes at different soil depths in *A. nilotica+D. sissoo* plantation

The percent organic carbon in macro-aggregates varied from 1.43% in 0-15cm depth to 0.32% in 60-100cm depth accounting for 30-40% of total carbon content of the soil. Micro-aggregates stored 0.85% in 0-15cm depth to 0.21% in 60-100cm while 0.63% in 0-15cm depth to 0.15% of organic carbon in 60-100cm depth was estimated in silt and clay associated fraction of soil structure down the soil depth. These differences through two way ANOVA were found to be significant between depths ($p<0.01$, 0.05) and significant between size classes ($p<0.05$). The soil carbon associated with micro-aggregates is supposed to be protected from degradation.

3.4 Monthly variations in CO_2 evolution rates from the soil of Acacia nilotica+Dalbergia sissoo plantation

Soil respiration or CO_2 evolution rates from the soil of *A. nilotica+D. sissoo* plantation ranged from 1.16 to 5.04g CO_2-C $m^{-2}d^{-1}$ with the highest rate of 5.04CO_2-C $m^{-2}d^{-1}$ in the month of August than other months indicating that rainy season accounted for higher soil respiration as compared to the dry months during the study period (Figure 5).

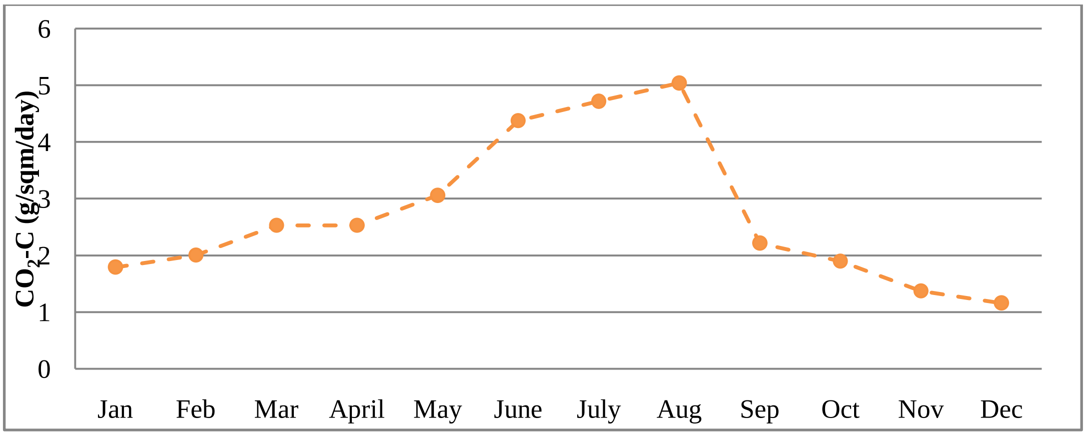

Figure 5: Monthly variations in CO_2 evolution rates from the soil of *A. nilotica+D. sissoo* plantation

The rate of soil respiration was found to be significantly correlated with soil moisture ($p<0.001$) and with soil temperature ($p<0.05$). Soil moisture explained 73% of the variation in soil respiration in *A. nilotica+D. sissoo* (Table 4).

Table 4: Nonlinear best fit regression equations w.r.t. value of the coefficient of determination (R^2) and Pearson correlation coefficient (r) of soil respiration as a function of soil moisture and soil temperature

Study Site	Parameter	Soil Moisture (%)	Soil Temperature (^{0}C)
A. nilotica* and *D. sissoo	**Equation**	$y = 0.012x^2 - 0.147x + 2.518$	$y = 0.523e^{0.067x}$
	R^2	0.730	0.519
	R	0.809*	0.654**

***significant (p<0.001); ** (p<0.05)**

3.5 Carbon Budget of the mixed plantation

The vegetation carbon pools of the plantation including the carbon added from litter fall were 43.35Mg/ha and soil carbon pools were 111.71Mg/ha. The mixed plantation of *A. nilotica* and *D. sissoo* accounted for 32.87Mg/ha as above ground carbon pool in and 8.57Mg/ha as below ground carbon pool in tree biomass. The carbon added to plantation floor through litter fall was 1.91Mg/ha/yr. The plantation accounted for a carbon flux of 2.27 Mg/ha/yr through photosynthesis in which above ground biomass contributed 1.80/ha/yr. The contribution from below ground components was 0.47Mg/ha/yr. The total soil carbon pool of the plantation was 111.71Mg/ha with 95.98Mg/ha as organic carbon pool and 15.73Mg/ha as inorganic carbon pool (Figure 6). The total carbon pool of *A. nilotica+D. sissoo* was thus estimated to be 155.06Mg/ha at the end of study period.

Discussion

Many studies have demonstrated that both natural vegetation restoration and tree plantation can significantly promote soil carbon storage [17-21]. Compared with tree plantation, natural vegetation restoration requires a long term process to restore the functioning of the ecosystem. Therefore, many countries, especially developing countries, have chosen tree plantation as a priority method of promoting ecosystem restoration and carbon sequestration [22]. Further, plantation forests are important sources of commercial forest products that alleviate the pressure on native forests and are viewed as an effective means of short-term carbon sequestration [23]. In India, the potential of short rotation forestry in sequestering carbon has been reported for poplar [5, 24, 25], eucalyptus, sal, teak [26, 27], leucaena, albizzia and acacia [28] species with annual rates of accumulation of carbon ranging from 1 Mg C/ha/yr in sal to 11.8 Mg C/ha/yr in poplar in the Indo Gangetic regions under irrigated conditions.

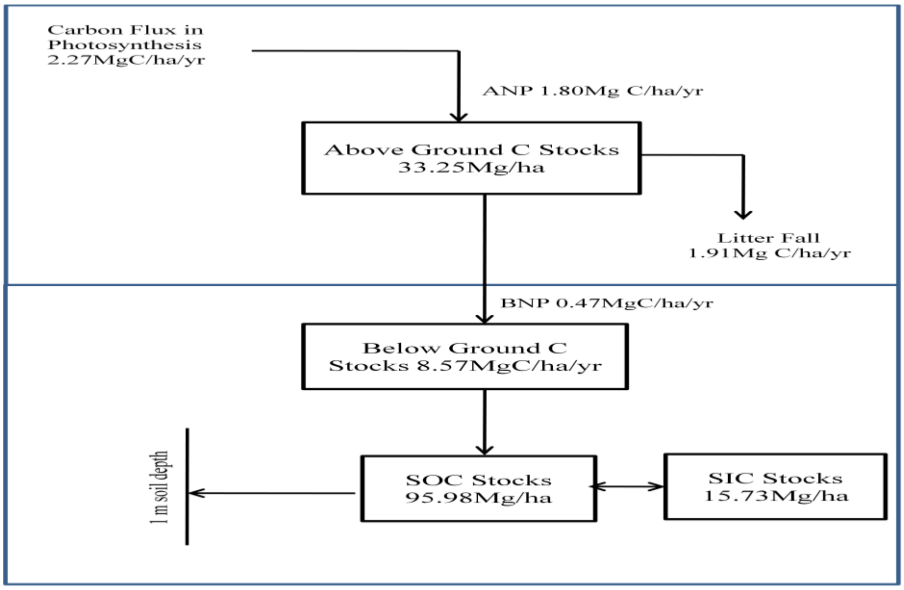

Figure 6: Carbon budget of *A.nilotica* and *D. sissoo* mixed plantation

Tree based systems accumulate large amount of biomass and sequester substantial amount of carbon in perennial tree components. Approximately 50-92% of the total tree biomass in plantation is stored mainly in tree trunks as aboveground [29-31]. In the present study also, the above ground biomass accounted for 79% of the total biomass of the plantation. Improvement of soil carbon is critical for the maintenance of soil fertility and productivity. Soil aggregates are important agents of soil organic carbon retention and protection against decomposition. It was observed that organic carbon concentration decreased from macroaggregates to microaggregates at various soil depths in the studied plantation. However, organic matter associated with macroaggregates easily gets mineralized than that associated with microaggregates. In the present study, microaggregates (250 μm-53 μm and <53 μm) formed a large fraction of soil aggregates and therefore protected most of soil organic carbon in the soil.

There are many relatively recent developments in society that shape how the public views forest management, e.g., environmental movements and organizations, global access to information, etc. [32, 33]. Accurate estimation of carbon storage in tropical forests is challenging, and it has been suggested that refinement of current estimates is crucial to understand the alterations in the global carbon cycle through land-cover change [34] so that and how forest cover maintenance and enhancement could be used to mitigate predicted climate change Social forestry schemes in this regard play a crucial role for the betterment of existing forest, creating new areas with tree cover with significant ecological and environmental benefits.

Less interference with natural growing system and adoption of best management practices can increase the carbon sequestration potential of the tree plantations. Therefore, for forests and plantations, to fully achieve their potential to address climate change, their governance must be improved as forestry projects can provide low-cost mitigation strategies for climate change as well as adequate standards of living by improved food security, reduced poverty and increased sources of income [35].

Conclusion

The present study indicated that the mixed plantation of *A. nilotica* and *D. sissoo* along with its high soil carbon pool (111.71Mg/ha) also had a considerable amount of vegetation carbon stocks (43.35Mg/ha) and thus can play an important role in mitigation of climate change. Healthy soil provides a wide range of ecosystem services for sustaining biological productivity. Soil organic carbon at surface layers and inorganic carbon (SIC) at deeper layers provided greater potential for carbon sequestration. There was stabilization of carbon within microaggregates (250 μm-53 μm and <53μm)), that can be related to soil organic carbon stability.

Tree plantations play an important role both in vegetation and soil and carbon sequestration. Considering the problems prevalent in pure plantations, planting mixed forest with different species in one stand is becoming more and more popular in worldwide plantation management programmes [36, 37]

There are many benefits attributed to planting a mixed plantation which includes more efficient nutrient use, conservation of site quality and biodiversity, enhanced yields over time, reduced risk of catastrophic damage from pests and disease outbreaks. Thus, the present study also emphasizes the promotion of tree plantation with mixed species for various land uses such as barren land, wasteland, agricultural lands, drylands, fallow lands and private lands etc.

Acknowledgement-The financial assistance in the form of University Research Scholarship (URS) to Pooja Arora from Kurukshetra University, Kurukshetra and laboratory and library facilities provided by Institute of Environmental Studies, KUK are greatly acknowledged.

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(2017) ; http://www.jmaterenvironsci.com