

Climate change smart option and doubling farmer's income through *Melia dubia*-based agri-silviculture system

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A field experiment was carried out to estimate biomass production, carbon stock and economic performance of *Melia dubia* under agri-silviculture system. The grain yields of pearl millet were significantly lower under *M. dubia* plantations (852–2920 kg ha⁻¹) compared to sole crop without trees (3182 kg ha⁻¹). Maximum biomass production of 6-yr-old *M. dubia* planting was recorded as 74.9 t ha⁻¹ and minimum was 53.9 t ha⁻¹. Contribution of *M. dubia* to total carbon stock and carbon dioxide sequestration was observed in the range 27.0–37.5 and 98.9–137.5 t ha⁻¹ respectively. The net returns obtained from the tree were lowest (₹ 116,134–182,885 ha⁻¹) when compared to the tree + crop (₹ 139,953–209,650 ha⁻¹) system. The lowest net returns were observed in sole crop without trees (₹ 27,351 ha⁻¹). Thus, *M. dubia* plantations contributed towards higher carbon dioxide sequestration and economic performance of agri-silviculture system was higher compared to sole crop.

Keywords: Agroforestry, biomass, carbon stock, *Melia dubia*.

AN important environmental concern in the recent past is climate change that has attracted the world's attention towards the role of agroforestry in increasing the carbon sink and maintaining CO₂ concentration in the atmosphere¹. At present, agroforestry is a pertinent and efficient land-use system for dryland site improvement and also for optimization of productivity of agricultural crops as well as forest crops². Here we study to what extent agroforestry mitigates and affects climate change.

CO₂ is a major greenhouse gas (GHG) responsible for the prevailing global climatic conditions, and the economic and profitable option for balancing atmospheric CO₂ levels are the trees which are considered to be a major sink of CO₂ (refs 3, 4). Hence the role of trees in carbon sequestration and climatic change mitigation is significant. Several studies have reported that the carbon stored in trees is 50% of their biomass^{3–8}.

Melia dubia, commonly called Malabar neem, belongs to the family Meliaceae. It is a fast-growing, deciduous tree with stout, straight, tall bole and wide-spreading branches, and suitable for agroforestry which is indigenous to the Western Ghats of southern India⁹. *M. dubia* can be used as a substitute for pulpwood¹⁰, with its copious uses like timber, fuelwood and plywood. Despite knowledge on agroforestry in sequestering carbon, there is still inadequate data on the agri-silviculture system contributing to climate change mitigation. Considering the above points, the present study was conducted with the primary objective of climate change mitigation and secondary benefits of fodder security and increased farm income. The study estimates biomass production, carbon stock, CO₂ sequestration and economics of agri-silviculture system under rainfed conditions.

A field experiment was carried out during *kharif* 2017 in 6-yr-old *M. dubia* plantations in the Agroforestry Research Block, AICRP on Agroforestry, Rajendranagar, Hyderabad. The experimental soil was slightly alkaline, high in organic carbon (0.77%), medium in available N (287.6 kg ha⁻¹), low in available P₂O₅ (41.31 kg ha⁻¹) and medium in available K₂O (214.0 kg ha⁻¹).

M. dubia was planted at a spacing of 5 m × 4 m with 500 trees ha⁻¹. No special management practices were followed for *M. dubia*, except application of organic manure and fertilizers during the first year of plantation and pruning during later stages. Pearl millet was intercropped with *M. dubia* during the first week of July 2017. Pearl millet variety PHB-3 was planted according to the Telangana state recommendations at a spacing of 45 cm × 15 cm with seed rate of 5 kg ha⁻¹. Organic manure was applied according to the treatments. Only pearl millet crops and not the trees were subjected to various treatments. The experiment was laid out in a randomized block design and replicated thrice; the treatments comprised of T₁: control (no fertilizer and manure), T₂: 100% recommended dose of fertilizers (RDF) through normal urea, T₃: 100% RDF through neem-coated urea, T₄: 75% recommended dose of nitrogen (RD N) + 25% N poultry manure, T₅: 75% RD N + 25% N farm yard manure (FYM), T₆: 75% RD N + *Pongamia* green leaf manure @ 10 t ha⁻¹, T₇: 75% RD N + *Azotobacter* @ 500 g ha⁻¹, T₈: sole crop without trees (100% RDF). The trees in these plots were chosen for observation, and 100% RDF to crop was 80–40–30 NPK kg ha⁻¹.

The height of all the trees in each plot was measured using a measuring tape fixed on a straight wooden stick from the ground level to the tip of the main branch. Girth at breast height (GBH) was measured at 1.37 m from the ground level over the bark with the help of measuring tape¹¹. Canopy spread was measured in East-West and North-South direction by placing four straight wooden poles at last shoot tip of the tree with measuring tape and the mean value was calculated^{4–6}.

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Table 1. Growth parameters of *Melia dubia* in agri-silviculture system under rainfed conditions

Treatment	Height (m)	Girth (cm)	Canopy spread (m)		Volume (m ³)
			N-S	E-W	
T ₁ : Control	9.85	50.03	4.39	4.45	0.22
T ₂ : 100% RDF through normal urea	9.53	46.83	5.01	4.53	0.18
T ₃ : 100% RDF through neem-coated urea	9.51	53.12	4.28	4.47	0.24
T ₄ : 75% RD N + 25% N through poultry manure	9.74	44.42	4.57	4.33	0.17
T ₅ : 75% RD N + 25% N through FYM	10.27	50.43	4.46	4.30	0.23
T ₆ : 75% RD N + PGLM @ 10 t ha ⁻¹	9.48	45.28	4.52	3.23	0.17
T ₇ : 75% RD N + <i>Azotobacter</i> @ 500 g ha ⁻¹	10.03	49.35	4.51	4.34	0.21
T ₈ : Sole crop without trees (80–40–30 NPK kg ha ⁻¹)	–	–	–	–	–
Mean	9.77	48.49	4.46	4.23	

100% RDF = 80–40–30 kg NPK ha⁻¹.

Table 2. Above-ground biomass (AGB) and below-ground biomass (BGB) of *M. dubia* in agri-silviculture system under rainfed conditions

Treatment	AGB	BGB	Total biomass
	t ha ⁻¹		
T ₁	55.4	14.4	69.9
T ₂	46.1	12.0	58.1
T ₃	59.5	15.5	74.9
T ₄	42.9	11.2	54.1
T ₅	57.1	14.9	72.0
T ₆	42.8	11.1	53.9
T ₇	53.3	13.9	67.1
T ₈	–	–	–
Mean	51.0	13.3	64.3

The following formula was used for calculating the standing volume of trees¹²

$$\text{Volume (m}^3\text{)} = \pi (D/2)^2 \times H,$$

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).

Non-destructive method of biomass estimation was carried out using volume (tree height, DBH) and wood density. Wood density of 6-yr-old *M. dubia* trees is 500.20 kg m⁻³ (ref. 13)

$$\begin{aligned} \text{Above-ground biomass (AGB; kg tree}^{-1}\text{)} \\ = \text{Volume (m}^3\text{)} \times \text{wood density (kg m}^{-3}\text{)}. \end{aligned}$$

Below-ground biomass (BGB) of the tree includes live root biomass, excluding fine roots and was calculated using 0.26 factor of root : shoot ratio³

$$\text{BGB (kg tree}^{-1}\text{)} = \text{AGB (kg tree}^{-1}\text{)} \times 0.26.$$

Sum of AGB and BGB gives total biomass (TB) of the tree^{4,14,15}

$$\text{TB (kg tree}^{-1}\text{)} = \text{AGB (kg tree}^{-1}\text{)} + \text{BGB (kg tree}^{-1}\text{)}.$$

A literature search revealed that carbon concentration in stem wood of *M. dubia* was 50% of the standing biomass^{16,17}. Therefore, carbon storage in stemwood of *M. dubia* was computed by fraction of biomass.

$$C \text{ (t ha}^{-1}\text{)} = 0.50 \times \text{TB (t ha}^{-1}\text{)},$$

where C is the carbon stock and TB is the total dry biomass. The CO₂ equivalents (quantity of $C \times 44/12$) were arrived from carbon stocks for calculating CO₂ sequestration (t ha⁻¹) by biomass of *M. dubia* trees in agri-silviculture system^{4,14}.

Table 1 lists height of the tree, GBH, canopy spread and volume. The results indicate that the height of 6-yr-old *M. dubia* trees varied between 9.48 and 10.27 m, with an average of 9.77 m. Similar findings were reported by Ashalatha *et al.*¹⁸ in *M. dubia* and Vanlalburzauva *et al.*¹⁹ in *Gmelina arborea*. GBH of trees ranged between 44.42 and 53.12 cm with an average of 48.49 cm. The N–S and E–W direction canopy spread was 4.28–5.01 and 3.23–4.53 m, with a mean of 4.46 and 4.23 m respectively. The volume of the trees (m³ tree⁻¹) varied from 0.17 to 0.24 m³ with an average value of 0.20 m³. Similar findings were reported by Rizvi *et al.*²⁰ in poplar trees in agri-silviculture system.

Table 2 shows biomass of the trees. AGB ranged between 42.7 and 59.5 t ha⁻¹, 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.*²¹ in *M. dubia*.

Table 3 provides results on carbon stock. Above-ground carbon recorded had a maximum value of 29.7 t ha⁻¹ and minimum of 21.4 t ha⁻¹. Below-ground carbon ranged between 5.6 and 7.7 t ha⁻¹, with an average value of 6.6 t ha⁻¹. Maximum total carbon of 37.5 t ha⁻¹ and minimum of 27.0 t ha⁻¹ were recorded in agri-silviculture system, with a mean of 32.1 t ha⁻¹. The total carbon sequestered by agri-silviculture system under rainfed conditions ranged from 98.9 to 137.5 t ha⁻¹. Average sequestration potential in agri-silviculture system was

Table 3. Carbon stock and carbon sequestration of *M. dubia* in agri-silviculture system under rainfed conditions

Treatment	Carbon stock (t ha ⁻¹)			Carbon sequestration (t ha ⁻¹)		
	Above ground	Below ground	Total	Above ground	Below ground	Total
<i>T</i> ₁	27.7	7.2	34.9	101.7	26.4	128.2
<i>T</i> ₂	23.1	6.0	29.1	84.7	22.0	106.7
<i>T</i> ₃	29.7	7.7	37.5	109.1	28.4	137.5
<i>T</i> ₄	21.5	5.6	27.0	78.7	20.5	99.2
<i>T</i> ₅	28.6	7.4	36.0	104.9	27.3	132.1
<i>T</i> ₆	21.4	5.6	27.0	78.5	20.4	98.9
<i>T</i> ₇	26.6	6.9	33.6	97.8	25.4	123.2
<i>T</i> ₈	—	—	—	—	—	—
Mean	25.5	6.6	32.1	93.6	24.3	118.0

found to be 118 t ha⁻¹ under rainfed conditions. Hence, fast-growing and long-living trees are efficient sinks for CO₂ storage. These results are in conformity with those of Prabha *et al.*⁵ in *M. dubia* under rainfed conditions.

As shown in Table 4, the grain yield of pearl millet varied from 852 to 3182 kg ha⁻¹, with a mean of 2073 kg ha⁻¹. The *T*₈ treatment recorded significantly higher yield (3182 kg ha⁻¹) which might be due to 100% RDF application that helped in equal distribution of nutrients to crop at various phenological stages and also due to better utilization of solar energy without any shade effect of trees. Reduced yield in pearl millet intercropped with *M. dubia* compared to sole crop without trees is due to reduced photosynthetic active radiation on crop canopy. The same has been reported in previous studies²²⁻²⁴.

The yield in *T*₇ was lowest (1187 kg ha⁻¹) because of lesser availability of nitrogen during initial crop growth period that affected the plant height, tiller number, leaf area, yield attributes and ultimately the yield. *T*₆ recorded on par yield (2667 kg ha⁻¹) with *T*₃ and significantly higher when compared with other treatments except *T*₈. This may be because, *Pongamia* which is leguminous and nitrogen fixing tree containing higher nitrogen content in leaf (2.75%) got mineralized and made available to crop that helped in better plant growth and development. *T*₃ recorded higher yield (2920 kg ha⁻¹) because of slow release of nitrogen and less loss of nutrients. The efficiency of neem coated urea is better when compared to normal prilled urea (*T*₂). And *T*₄ (1983 kg ha⁻¹) was comparatively better than *T*₅ (1443 kg ha⁻¹), which might be due to higher nutrient content in the former and less C : N ratio in the latter. The integrated use of chemical fertilizers and poultry manure helped to serve the purpose of quick availability of nutrients using chemical fertilizers and slow, prolonged availability using poultry manure that paved the way for crop growth and development resulting in more yield than *T*₅ > *T*₇ > *T*₁ (ref. 25).

Table 5 shows data related to the economics of pearl millet in *M. dubia*-based agri-silviculture system. The highest gross returns (₹ 41,339 ha⁻¹) were observed in sole crop followed by *T*₃ (₹ 40,753 ha⁻¹), *T*₂ (₹ 39,673 ha⁻¹),

*T*₆ (₹ 38,000 ha⁻¹), *T*₄ (₹ 35,820 ha⁻¹), *T*₅ (₹ 28,568 ha⁻¹) and *T*₇ (₹ 19,910 ha⁻¹). Although cost of cultivation was less in *Azotobacter*, gross returns were also less due to reduced grain yields.

Net returns and benefit : cost ratio (B : C) ratio were recorded highest with *T*₈ (₹ 27,351 ha⁻¹ and 2.96) followed by *T*₃ (₹ 26,765 ha⁻¹ and 2.91), *T*₂ (₹ 25,723 ha⁻¹ and 2.84) and *T*₆ 10 t ha⁻¹ (₹ 23,819 ha⁻¹ and 2.68). Lowest gross returns (₹ 12,136 ha⁻¹), net returns (₹ 2976 ha⁻¹) and B : C ratio (1.32) were registered under control treatment.

Reduced income from crop in agri-silviculture system compared to sole crop can be recuperated from the income obtained through *M. dubia* trees²⁴. Use of organic manure increased the cost of cultivation and resulted in lesser B : C ratio compared to 100% RDF treatments. The results were in accordance with the findings of Anand *et al.*²⁶ and Patel *et al.*²⁷. In spite of lower net returns from organic manure in the short run, higher returns with better soil fertility, quality produce and reduced environmental problems were obtained in the long run.

Table 5 depicts the economics of the tree. Cost of cultivation of *M. dubia* from the first to sixth year was calculated to be ₹ 55,000 ha⁻¹. Gross returns from 6-yr-old trees ranged from ₹ 171,134 ha⁻¹ to ₹ 237,885 ha⁻¹ (Table 5), with an average of ₹ 204,092 ha⁻¹. The net returns of tree varied from ₹ 116,134 ha⁻¹ to ₹ 182,885 ha⁻¹, with a mean of ₹ 149,092 ha⁻¹. B : C ratio ranged from 3.11 to 4.33, with an average of 3.71.

Table 5 also presents the economics of the system (tree + crop). Maximum gross returns (₹ 207,444–278,638 ha⁻¹) and net returns (₹ 139,953–209,650 ha⁻¹) were recorded in the agri-silviculture system (tree + crop) and minimum gross returns (₹ 41,339 ha⁻¹) and net returns (₹ 27,351 ha⁻¹) were recorded in the sole crop without trees¹⁸. Thus, it is evident that intercropping of pearl millet with *M. dubia* shows maximum gross and net monetary returns when compared to sole cropping of pearl millet. Improved monetary returns from the system (tree + crop) are mainly due to additional advantage of value-added products from the tree in the form of timber,

Table 4. Economics of crop and tree as influenced by nutrient management in *M. dubia*-based agri-silviculture system

Treatment	Grain yield (kg ha ⁻¹)	Crop (₹ ha ⁻¹)				Tree (₹ ha ⁻¹)			
		Cost of cultivation	Gross return	Net return	B : C ratio	Cost of cultivation	Gross return	Net return	B : C ratio
T ₁	852	9,160	12,136	2,976	1.32	55,000	221,755	166,755	4.03
T ₂	2340	13,950	39,673	25,723	2.84	55,000	184,554	129,554	3.36
T ₃	2920	13,988	40,753	26,765	2.91	55,000	237,885	182,885	4.33
T ₄	1983	15,156	35,820	20,664	2.36	55,000	171,624	116,624	3.12
T ₅	1443	15,781	28,568	12,787	1.81	55,000	228,588	173,588	4.16
T ₆	2667	14,181	38,000	23,819	2.68	55,000	171,134	116,134	3.11
T ₇	1187	13,106	19,910	6,804	1.52	55,000	213,105	158,105	3.87
T ₈	3182	13,988	41,339	27,351	2.96	—	—	—	—
Mean	2073	—	—	—	—	—	204,092	149,092	3.71

*Cost of plywood @ ₹ 4000 t⁻¹.

Table 5. Economics of agri-silviculture system (tree + crop) as influenced by nutrient management in *M. dubia*-based agri-silviculture system

Treatment	Cost of cultivation (₹ ha ⁻¹)	Gross return (₹ ha ⁻¹)	Net return (₹ ha ⁻¹)	B : C ratio
T ₁	64,160	233,892	169,732	5.36
T ₂	68,950	224,227	155,277	6.20
T ₃	68,988	278,638	209,650	7.24
T ₄	70,156	207,444	137,288	5.48
T ₅	70,781	257,156	186,375	5.97
T ₆	69,181	209,134	139,953	5.79
T ₇	68,106	233,015	164,909	5.39
T ₈	13,988	41,339	27,351	2.96

plywood and fodder coupled with better performance of pearl millet⁷. This clearly shows that arable crops like pearl millet when grown as an intercrop with the trees exhibit compatibility with the trees in mutual sharing of the natural resources available. Agroforestry practices may fetch higher returns when compared to sole crops²⁸.

Agroforestry mitigates climate change through carbon sequestration. Growing of trees only for carbon is not a feasible choice for farmers in the irrigated agro-ecosystem, but the carbon market is gearing up in the present and demand is yet to increase in the near future, creating additional revenue in terms of carbon trading. The present study highlights, *Melia dubia* + pearl millet agri-silvi system as a better option than the sole agricultural cropping, not only for climate mitigation but also for sustainable productivity and doubling farmer's income. Hence, it is required to proceed with the system; otherwise the profit gained in-terms of carbon sequestration in the system would revert to the original state.

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Energy use pattern in wheat crop production system among different farmer groups of the Himalayan Tarai region

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This study examines the energy use pattern in wheat crop cultivation in the Himalayan Tarai region of India among different farmer groups. A total of 250 farmers from 59 villages were interviewed and information on various inputs in wheat crop production was collected during 2015–16. Based on the information, all the inputs in wheat crop production were identified and converted into energy using standard energy equivalents. Results showed that the total energy expenditure in wheat crop production in the region was 20497.1 MJ/ha in which fertilizer, fuel and seed shared 85% of the total energy. Fertilizer alone accounted for 50.2% of total energy followed by fuel (22.6%). It was estimated that farmers of the large and medium category used more energy compared to those having small landholding, but also produced more grains. Operation-wise, fertilizer application consumed maximum energy followed by tillage operation. The average value estimated for output-to-unit input energy ratio was 3.02, whereas it was 3.26, 3.15, 3.14, 3.11 and 2.95 for large, medium, semi-medium, small and marginal category farmers respectively. It can be concluded from the present study that energy consumption has a positive relationship with yield.

Keywords: Agriculture, energy use pattern, farmer groups, wheat crop.

MODERN-DAY agriculture crop production requires high input of fossil energy, which is consumed as ‘direct energy and indirect energy (energy expended beyond the farm for the manufacture of fertilizers, plant protection agents, machines, etc.)¹. Global food security demands an increase in agriculture production as total cultivable land is decreasing and the world population is increasing day by day². In general, various alternatives for increasing agricultural production can be characterized in the form of additional land use, increase in yield per unit area and increased cropping intensity. As it is not possible to increase cultivable land for agriculture production, the substantial change in production may be increased by increasing the use of input resources³. Production of wheat crop directly depends on high-yielding varieties,

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