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Carbon Sequestration Potential of Melia Dubia Progenies and Plantations with Varied Spatial Geometries at Different Age Gradations in South Gujarat

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ABSTRACT

We evaluated Melia dubia for carbon sequestration potential under two different studies. First studies comprised of 17 open pollinated progenies planted at 3×3 m and the second one was plantations of same species at 2×2, 3×2, 3×3 and 4×2 m spatial geometries under randomized block design. The progeny evaluation study revealed that at the age of 5 years, progeny GJ09 produced maximum biomass (95.61 t/ha) with average maximum productivity of 19.12 t/ha/year, carbon stocks and carbon sequestration to tune of 48.76 t/ha and 178.95 t/ha, respectively. Further, progeny GJ09 showed carbon stock and carbon sequestration rate of 9.75 t/ha/year and 35.79 t/ha/year, respectively. The spatial geometry evaluation studies deduced that there was significant variation in biomass productivity, carbon stock and carbon sequestration among individuals under different spatial geometries. Although, at the age of 5-years, the individual tree biomass, carbon stock and carbon sequestration was maximum under 4×2 m spacing. However, at the 5-years of age, owing to the maximum tree per hectare 2×2 m spatial configuration provided highest biomass (20.29 t/ha/year), carbon stocks (10.35 t/ha/year) and carbon sequestration potential (24.94 t/ha/year). These studies revealed that M. dubia being fast growing species has great potential for carbon sequestration. The progenies with higher sequestration rate can be utilized for further planation programmes.

INTRODUCTION

Carbon sequestration is the long-term storage or removal of that CO2 in geological, biological, or ocean sinks. Climate change certainly is one of the most demanding environmental challenges being witnessed in world today. The speedy increase in atmospheric carbon dioxide (CO_2) and other greenhouse gases due to human activities such as industrialization, fossil fuel combustion, and deforestation has led to momentous changes in global climate systems. The increasing concentration of atmospheric carbon dioxide is a primary driver of global warming. Among the various strategies proposed to mitigate climate change, carbon sequestration has appeared as a vital natural answer. Manmade plantations, agroforests and forest ecosystems play a vital role in this process by acting as natural carbon sinks (Lal, 2008; Thakur *et al.*, 2011; Panwar *et al.*, 2022). This capacity to capture and store carbon helps offset emissions produced by human activities. The Intergovernmental Panel on Climate Change (IPCC) has underlined the importance of forests and tree-based ecosystems in mitigating climate change by enhancing carbon sequestration (FAO, 2020; IPCC, 2022). Sustainable forest management, afforestation, and reforestation initiatives are therefore widely recommended as practical and cost-effective strategies to reduce atmospheric carbon levels. Urban forestry and agroforestry systems also contribute significantly to carbon sequestration. Agroforestry practices, which integrate trees with agricultural crops or livestock systems, enhance carbon storage while simultaneously improving soil productivity and agricultural sustainability (Bhusara *et al.,* 2016). These integrated systems are increasingly recognized as important strategies for climate-smart agriculture. Globally, governments and i n t e rnational organizations are promoting tree-based climate solutions through various environmental programs and policies. Initiatives such as afforestation, reforestation, and forest conservation are increasingly emphasized as part of climate mitigation strategies. Organizations such as the United Nations Environment Programme and the Food and Agriculture Organization advocate for sustainable forest management and restoration of degraded landscapes to increase carbon sequestration capacity (UNEP, 2021). These initiatives not only help mitigate climate change but also contribute to achieving

sustainable development goals related to biodiversity conservation, poverty reduction, and environmental protection. Carbon sequestration by trees is a vital natural process that plays a key role in mitigating climate change and maintaining ecological balance (Luna *et al.,* 2016; UNEPA, 2023).

India's nationally determined contribution (NDC), to sequester an additional 2.5 to 3-billion-ton carbon dioxide (CO2) equivalent by 2030 under the Paris Climate agreement, can be achieved by integrating trees in multiple land uses (Ruchika, 2019). In this direction, many industrially important fast growing species are already popular among the farmers and are integrated either under agroforestry or as sole plantations. These species provide a sustainable alternative to low-carbon land use systems, offering high yields of renewable woody biomass along with multiple ecosystem benefits (Luna *et al.,* 2009, 2011, 2014; Panwar *et al.,* 2022; Jinger *et al.,* 2024). Still we need to look for indigenous multipurpose tree species which could be utilized in wood based industries on one hand and have high carbon sequestration potential in shorter period leading to achieve NDC at national level sustainable development goals globally. One such species is *Melia dubia*. This species has already explored for its multipurpose potential (Sinha *et al.,* 2019; Sukhadiya *et al.,* 2021; Malek *et al.,* 2024) and is being cultivated as potential agroforestry ideotype (*Bhusara et al.,* 2018; Thakur *et al.,* 2018; Mohanty *et al.,* 2019). Its potential for carbon sequestration has not been explored much so far. Therefore, the present study intended to put forth the carbon sequestration potential different progenies and plantations done at varying spatial geometries in southern Gujarat.

MATERIALS AND METHODS

Edapho-climatic conditions of site

The investigation was carried out at the College of Forestry, Navsari Agricultural University, Navsari (20.95N latitude, 75.90E longitude with an altitude of 10 m amsl), Gujarat, India, during 2014-2019. Climate of area is characterized humid and warm with monsoon rainfall of around 1500 mm (June- September), moderately cold in winter (November- February) and fairly hot and humid in summer (March-May). Soils of experimental site is deep black originated from old alluvium of basaltic material, taxonomically placed under the group of *Ustochrepts*, sub group of *verti Ustochrepts*, sub order of *orchrepts* and order of *inceptisols*, characterized by clay, deep, moderately drained with good water holding capacity. The soil cracks heavily on drying and expands on wetting and predominant clay mineral found to be montmorillonite. Soil pH and average available nitrogen, phosphorus, potassium, and organic carbon of experimental site was 225.79 kg ha-1, 32.81 kg ha-1, 310.34 kg ha-1, 7.67 and 0.87%, respectively.

Experimental details

The study-1 was conducted in randomized block design with 17 open pollinated *Melia dubia* Cav. progenies as treatments with three replications (three individuals in each replication). The seeds of 16 families were supplied by Division of Genetics and Tree Improvement, Forest Research Institute Dehradun, Uttarakhand, India and family named GJ09 was local source (collected from Northern most tip of Western Ghats), which were collected from South Gujarat, India. Planting was carried out in January, 2014 at 3x3 m spacing with boundary row to avoid edge effect.

The study-2 was comprised of *Melia dubia* plantations at with spatial geometries of 2×2, 3×2, 3×3 and 4×2 m. Both the experiments managed following normal tree management practices. No additional fertilizer (organic or inorganic) was applied throughout the period and trees were allowed to natural pruning after 2nd year onwards.

Above ground biomass

The tree height and diameter at breast height (DBH; at 1.37 cm above ground) were recorded (from 1st to 5th years of age) periodically following standard methods in each replication (3 tree/replication in progeny evaluation and 5 trees per replication in spatial geometry evaluation) of each family. Standing tree fresh biomass was calculated following regression equations B=0.0299(HD2)+7.48

(Thakur *et al.,* 2021), Where, B =total tree fresh biomass, H=height (m) of the tree and D= DBH (cm). Estimated fresh biomass was converted to dry mass *i.e.* 50 per cent of the fresh biomass (Laxmai *et al.,* 2021).

Belowground Biomass

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

BGB (t ha-1) = AGB (t ha-1) × 0.26

Total Biomass (TB)

Sum of AGB and BGB gives total biomass (TB) of the tree (Ravindranath and Ostwald, 2008).

TB (t ha-1) = AGB (t ha-1) + BGB (t ha-1)

Carbon stock and carbon sequestration

Then biomass was converted to total carbon stock by multiplying factor of 0.51 (Dury *et al.,* 2002) and carbon sequestration by multiplying the carbon stock by factor of 3.67 (Van-Kooten, 1999).

Statistical analysis

The data generated were subjected to the statistical analysis following randomized block design (RBD) and ANOVA was constructed. Further, Duncan's multiple range test (DMRT) was used to compare the sets of means of each treatment following Sheoran (n.d.). OPSTAT - Online Statistical Analysis Tools. CCS HAU, Hisar. http://14.139.232.173/opstat/ default.asp.

RESULTS AND DISCUSSION

Carbon Sequestration potential of Melia dubia progenies

Biomass productivity

The results indicated that biomass production (kg/tree and ton/ha; dry weight basis) varied significantly (p<0.05) amongst the 17 progenies (Table 1). In the 1st, 2nd and 3rd year the maximum biomass production (9.05, 24.3 and 37.00 kg/tree and 10.05, 27.00 and 41.10 t/ha, respectively) was put up by progeny number 259. At the age of two years, biomass production (21.83 kg/tree and

24.25 t/ha) by progeny 260 was at par with that of 259. At the age of 4 years, highest biomass production (53.85 kg/tree and 59.83 t/ha) was of progeny GJ09, which however was statistically at par with progeny 260. However, at the age of 5 years (Table 1), GJ09 put up maximum biomass (86.06 kg/tree and 95.61 t/ha) with average maximum productivity of 17.21 kg/tree/year and 19.12 t/ha/year (Fig. 1a and b). The minimum biomass production and productivity was of progeny 270 at the age of 5 years.

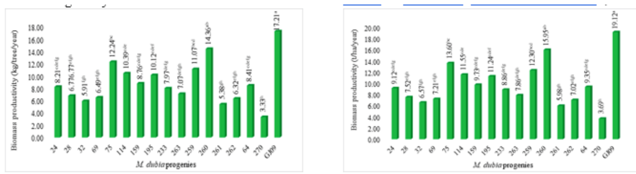

Figure 1. Variation in a) per tree [SE(m)±1.26] and b) per hectare biomass productivity [SE(m)±1.40] by M. dubia progenies in South Gujarat, means with different superscript letter in each bar indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

Carbon stock and carbon sequestration

The results expressed that carbon stocks varied significantly among the progenies and the age gradations (Table 2). Among the 17 progenies, 259 progeny acquired maximum carbon stock amounting to 4.61, 12.39 and 18.87 kg/tree and 5.13, 13.77 and

20.96 t/ha from 1st to 3rd year of age. At 2nd year progeny 260 had at par carbon stock with 259. Progeny GJ09 showed highest carbon stock amounting to 27.47 and

43.89 kg/tree and 30.51 and 48.76 t/ha at 4th and 5th year, respectively. However, at 4th year progeny 260 was at par with GJ09 (Table 2). Minimum carbon stocks were of family 270 at 5 years of age.

Further, owing to maximum carbon stock, progeny 259 sequestered maximum carbon of 16.94, 45.49 and

69.25 kg/tree and 18.82, 50.53 and 76.94 t/ha at age of 1st, 2nd and 3rd year (Table 3). However, at 4th and 5th year, the maximum carbon sequestration (100.80 and

161.07 kg/tree and 111.99 and 178.95 t/ha) was of GJ09. Progeny 260 sequestered statistically at par carbon to that of GJ09. Progeny 270 sequestered minimum carbon at the age of 5 years.

Carbon stock and carbon sequestration potential

The results pinned out that the carbon stock and carbon sequestration potential of *M. dubia* progenies varied significantly at the age of 5 years (Fig. 2 and 3). Maximum carbon stock (8.78 kg/tree/year and 9.75 t/ha/year) and carbon sequestration (32.21

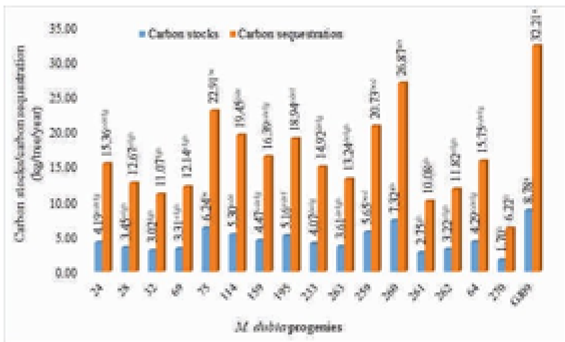

Figure 2. Variation in individual tree carbon stocks [SE(m)±0.64] and carbon sequestration [SE(m)±2.36] by M. dubia progenies in South Gujarat, means with different

superscript letter in each bar indicate significant difference ($p<0.05$) according to Duncan's Multiple Range Test

Table 1. Variation in biomass production of *M. dubia* progenies in South Gujarat

Progeny	Dry biomass (kg/tree)					Dry biomass (t/ha)				
	Age (years)									
	1	2	3	4	5	1	2	3	4	5
24	6.94bc	17.14b	25.47bcd	30.40bcde	41.04cdefg	7.71bc	19.04b	28.3bcd	33.77bcde	45.60cdefg
28	5.64cd	11.43de	17.89def	25.18def	33.85efgh	6.26cd	12.7de	19.88def	27.98def	37.6efgh
32	5.12d	10.17de	15.71ef	19.97ef	29.56fgh	5.68d	11.3de	17.45ef	22.18ef	32.84fgh
69	5.57cd	8.92de	18.82de	26.64cdef	32.44efgh	6.19cd	9.91de	20.91de	29.6cdef	36.04efgh
75	7.44b	16.44bc	28.47bc	37.41bcd	61.21bc	8.27b	18.26bc	31.63bc	41.56bcd	68.01bc
114	5.02d	8.55de	24.84bcd	42.27ab	51.96cde	5.58d	9.5de	27.6bcd	46.96ab	57.73cde
159	5.67cd	9.32de	18.57de	22.89def	43.79cdefg	6.29cd	10.36de	20.63de	25.43def	48.65cdefg
195	7.29b	20.68ab	28.41bc	40.73abc	50.6cdef	8.1b	22.97ab	31.56bc	45.25abc	56.22cdef
233	4.91d	7.82de	11.42ef	22.47def	39.87defg	5.45d	8.69de	12.69ef	24.97def	44.29defg
263	5.99bcd	12.14cd	20.3cde	28.19bcde	35.37defgh	6.66bcd	13.49cd	22.55cde	31.31bcde	39.29defgh
259	9.05a	24.3a	37.00a	41.67abc	55.37bcd	10.05a	27.00a	41.10a	46.29abc	61.52bcd
260	6.46bcd	21.83a	32.61ab	52.08a	71.79ab	7.18bcd	24.25a	36.23ab	57.86a	79.75ab
261	5.38d	9.9de	13.52ef	17.03ef	26.92gh	5.98d	11de	15.02ef	18.92ef	29.91gh
262	4.9d	7.00e	14.32ef	29.23bcde	31.59efgh	5.45d	7.77e	15.91ef	32.47bcde	35.1efgh
64	4.93d	9.79de	14.69ef	28.50bcde	42.07cdefg	5.48d	10.87de	16.32ef	31.66bcde	46.74cdefg
270	4.92d	6.63e	8.87f	12.32f	16.63h	5.46d	7.37e	9.85f	13.68f	18.47h
GJ 09	6.36bcd	20.93ab	32.67ab	53.85a	86.06a	7.06bcd	23.25ab	36.30ab	59.83a	95.61a
SE(m)±	0.46	1.50	2.68	4.56	6.31	0.51	1.67	2.97	5.06	7.01

Means with different superscript letter in the same column indicate significant difference (*p*$<$0.05) according to Duncan's Multiple Range Test

Table 2. Variation in carbon stocks of *M. dubia* progenies in South Gujarat

Progeny	Carbon stocks (kg/tree)					Carbon stocks (t/ha)				
	Age (years)									
	1	2	3	4	5	1	2	3	4	5
24	3.54bc	8.74b	12.99bcd	15.50bcde	20.93cdefg	3.93bc	9.71b	14.43bcd	17.22bcde	23.26cdefg
28	2.87cd	5.83de	9.12def	12.84def	17.26efgh	3.19cd	6.48de	10.14def	14.27def	19.18efgh
32	2.61d	5.19de	8.01ef	10.18ef	15.08fgh	2.90d	5.77de	8.90ef	11.31ef	16.75fgh
69	2.84cd	4.55de	9.60de	13.59cdef	16.55efgh	3.16cd	5.06de	10.66de	15.10cdef	18.38efgh
75	3.80b	8.38bc	14.52bc	19.08bcd	31.22bc	4.22b	9.31bc	16.13bc	21.20bcd	34.68bc
114	2.56d	4.36de	12.67bcd	21.56ab	26.50cde	2.84d	4.84de	14.08bcd	23.95ab	29.44cde
159	2.89cd	4.76de	9.47de	11.67def	22.33cdefg	3.21cd	5.28de	10.52de	12.97def	24.81cdefg
195	3.72b	10.55ab	14.49bc	20.77abc	25.81cdef	4.13b	11.72ab	16.10bc	23.08abc	28.67cdef
233	2.50d	3.99de	5.82ef	11.46def	20.33defg	2.78d	4.43de	6.47ef	12.73def	22.59defg
263	3.06bcd	6.19cd	10.35cde	14.37bcde	18.04defgh	3.40bcd	6.88cd	11.5cde	15.97bcde	20.04defgh

259	4.61a	12.39a	18.87a	21.25abc	28.24bcd	5.13a	13.77a	20.96a	23.61abc	31.37bcd
260	3.30bcd	11.13a	16.63ab	26.56a	36.61ab	3.66bcd	12.37a	18.48ab	29.51a	40.67ab
261	2.74d	5.05de	6.9ef	8.69ef	13.73gh	3.05d	5.61de	7.66ef	9.65ef	15.26gh
262	2.50d	3.57e	7.30ef	14.91bcde	16.11efgh	2.78d	3.96e	8.11ef	16.56bcde	17.9efgh
64	2.52d	4.99de	7.49ef	14.53bcde	21.46cdefg	2.79d	5.55de	8.32ef	16.15bcde	23.84cdefg
270	2.51d	3.38e	4.52f	6.28f	8.48h	2.79d	3.76e	5.02f	6.98f	9.42h
GJ 09	3.24bcd	10.67ab	16.66ab	27.47a	43.89a	3.60bcd	11.86ab	18.51ab	30.51a	48.76a
SE(m)±	0.23	0.77	1.37	2.32	3.22	0.26	0.85	1.52	2.58	3.58

Means with different superscript letter in the same column indicate significant difference ($p<0.05$) according to Duncan's Multiple Range Test

Table 3. Variation in carbon sequestration of *M. dubia* progenies in South Gujarat

Progeny	Carbon sequestration (kg/tree)					Carbon sequestration (t/ha)				
	Age (years)									
	1	2	3	4	5	1	2	3	4	5
24	12.98bc	32.08b	47.67bcd	56.89bcde	76.82cdefg	14.42bc	35.64b	52.96bcd	63.21bcde	85.35cdefg
28	10.55cd	21.39de	33.49def	47.13def	63.35efgh	11.72cd	23.77de	37.21def	52.37def	70.38efgh
32	9.58d	19.04de	29.40ef	37.37ef	55.33fgh	10.64d	21.16de	32.66ef	41.52ef	61.47fgh
69	10.43cd	16.7de	35.23de	49.87cdef	60.72efgh	11.59cd	18.55de	39.14de	55.40cdef	67.46efgh
75	13.93b	30.77bc	53.28bc	70.02bcd	114.57bc	15.48b	34.19bc	59.20bc	77.79bcd	127.29bc
114	9.40d	16.00de	46.5bcd	79.11ab	97.25cde	10.44d	17.78de	51.66bcd	87.89ab	108.05cde
159	10.61cd	17.45de	34.76de	42.84def	81.96cdefg	11.78cd	19.39de	38.62de	47.6def	91.06cdefg
195	13.65b	38.7ab	53.17bc	76.24abc	94.72cdef	15.16b	43.00ab	59.07bc	84.70abc	105.23cdef
233	9.19d	14.64de	21.37ef	42.06def	74.62defg	10.21d	16.27de	23.75ef	46.73def	82.91defg
263	11.22bcd	22.72cd	38.00cde	52.75bcde	66.19defgh	12.46bcd	25.24cd	42.21cde	58.61bcde	73.54defgh
259	16.94a	45.49a	69.25a	77.99abc	103.64bcd	18.82a	50.53a	76.94a	86.65abc	115.14bcd
260	12.10bcd	40.86a	61.03ab	97.48a	134.36ab	13.44bcd	45.39a	67.81ab	108.30a	149.27ab
261	10.07d	18.53de	25.31ef	31.88ef	50.39gh	11.19d	20.59de	28.12ef	35.42ef	55.99gh
262	9.18d	13.10e	26.8ef	54.71bcde	59.12efgh	10.20d	14.55e	29.77ef	60.78bcde	65.69efgh
64	9.23d	18.32de	27.49ef	53.34bcde	78.75cdefg	10.26d	20.35de	30.54ef	59.26bcde	87.49cdefg
270	9.20d	12.41e	16.60f	23.05f	31.12h	10.22d	13.79e	18.44f	25.61f	34.57h
GJ 09	11.90bcd	39.17ab	61.15ab	100.80a	161.07a	13.22bcd	43.52ab	67.94ab	111.99a	178.95a
SE(m)±	0.85	2.81	5.01	8.53	11.81	0.95	3.12	5.57	9.48	13.13

Means with different superscript letter in the same column indicate significant difference ($p<0.05$) according to Duncan's Multiple Range Test

kg/tree/year and 35.79 t/ha/year) potential was of progeny Gj09. Progeny 260 showed statistically at par carbon stock (7.32 kg/tree/year and 8.13 t/ha/year) and carbon sequestration potential (26.87 kg/tree/year and 29.85 t/ha/year) to progeny Gj09. Minimum carbon stock and carbon sequestration rate was of progeny 270 (Fig. 2 and 3).

Carbon sequestration potential of M. dubia under spatial geometries

The results expressed that biomass production and productivity of *M. dubia* differed significantly ($p<0.05$) under different spatial configurations (Table 4). At 1- year of age, maximum individual tree biomass (7.39 kg/tree), carbon stock (7.77 kg/tree) and carbon sequestration (13.84

kg/tree) was maximum in 3x2 m spaced plantations. In 2nd, 3rd and 4th years of age maximum per tree biomass (15.90, 26.10 and 37.24 kg), carbon stock (8.11, 13.31 and 18.99 kg) and carbon sequestration (29.76, 48.85 and 69.70 kg) was recorded under 3x3 m planting geometry (Table 4). At 5 years' age of trees in 4x4 m spatial geometry provided highest biomass, carbon stock and carbon sequestration to the tune of 53.30, 27.18 and 99.77 kg/tree, respectively.

Owing to maximum number of trees under 2x2 m spaced plantations (table 4), from 1st till 5th year of age, provided significantly highest biomass (18.07, 25.42,

41.23, 69.09 and 101.46 t/ha), carbon stocks (9.21, 12.97, 21.03, 35.24 and 51.75 t/ha) and carbon sequestration (33.82, 47.59, 77.16, 29.31 and 189.91 t/ha). The data in figure 4a and 5a pinned out that the individual tree biomass productivity, carbon stock and carbon sequestration potential amounting to 10.66,

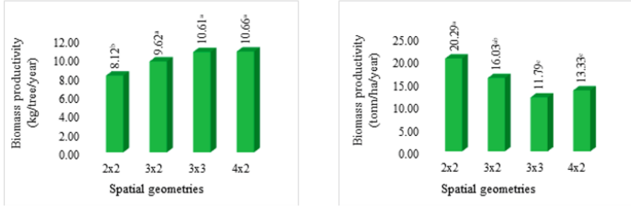

Figure 4. Variation in per tree [SE(m)± 0.45] and per hectare biomass [SE(m)± 0.76] productivity of M. dubia at the age 5 years under different spatial geometries in South Gujarat, means with different superscript letter in each bar indicate significant difference ($p<0.05$) according to Duncan's Multiple Range Test

5.44 and 9.95 kg/tree was under 4x2 m spatial configuration. However, as a results of maximum tree stocking per hectare, 2x2 m spaced plantations provided highest biomass productivity (20.29 t/ha/year), carbon stocks (10.35 t/ha/year) and carbon sequestration potential to the tune of 24.94 t/ha/year (Fig. 4b and 5b).

The variation in growth and productivity of tree species varies from location to location due to edapho- climatic attributes and genetic worth of material (Lodhiyal *et al.*, 2002; Luna *et al.* 2009; Luna *et al.* 2011, Thakur *et al.* 2023). The productivity of *M. dubia* in the present study is comparable with that reported in some of the released varieties of *M. composita* (Kumar *et al.*, 2017).

Table 4. Variation in biomass production, carbon stock and carbon sequestration of *M. dubia* under different spatial geometries in South Gujarat

Spatial geometry (m)	Age (years)									
	1	2	3	4	5	1	2	3	4	5
	Biomass (kg/tree)					Biomass (t/ha)				
2x2	7.23a	10.17c	16.49c	27.64c	40.58b	18.07a	25.42a	41.23a	69.09a	101.46a
3x2	7.39a	11.95bc	18.64bc	34.04ab	48.10a	12.31b	19.92b	31.06b	56.72b	80.13b
3x3	6.39b	15.90a	26.10a	37.24a	53.06a	7.10d	17.67bc	28.99b	41.37c	58.95c
4x2	7.21a	12.54b	21.97b	32.76b	53.30a	9.01c	15.68c	27.47b	40.96c	66.63c
SE(m)±	0.17	0.59	1.14	1.22	2.25	0.29	1.00	1.83	1.85	3.78
	Carbon stocks (kg/tree)					Carbon stocks (t/ha)				
2x2	3.69a	5.19c	8.41c	14.09c	20.70b	9.21a	12.97a	21.03a	35.24a	51.75a
3x2	3.77a	6.1bc	9.51bc	17.36ab	24.53a	6.28b	10.16b	15.84b	28.93b	40.86b
3x3	3.26b	8.11a	13.31a	18.99a	27.06a	3.62d	9.01bc	14.79b	21.10c	30.06c
4x2	3.68a	6.40b	11.21b	16.71b	27.18a	4.60c	8.00c	14.01b	20.89c	33.98c
SE(m) ±	0.09	0.30	0.58	0.62	1.15	0.15	0.51	0.93	0.94	1.93
	Carbon sequestration (kg/tree)					Carbon sequestration (t/ha)				
2x2	13.53a	19.03c	30.87c	51.73c	75.96b	33.82a	47.59a	77.16a	129.31a	189.91a
3x2	13.84a	22.38bc	34.90bc	63.72ab	90.02a	23.05b	37.28b	58.14b	106.16b	149.97b
3x3	11.96b	29.76a	48.85a	69.70a	99.31a	13.28d	33.07bc	54.27b	77.44c	110.34c
4x2	13.49a	23.48b	41.13b	61.33b	99.77a	16.87c	29.35c	51.41b	76.66c	124.71c
SE(m) ±	0.32	1.11	2.13	2.29	4.22	0.55	1.87	3.42	3.46	7.08

Means with different superscript letter in the same column indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

Jinger *et al.* (2025) have reported carbon stocks of 16.39 t/ha to 58.30 t/ha, and carbon sequestration to the tune of 60.20 t/ha and 214.20 t/ha in sole *M. dubia* plantation and under agroforestry (*M. dubia*+Lemon grass) systems in central Gujarat India at the age of 5 years spaced at 3 × 3 m. These findings are in congruity with our range carbon sequestration at same spacing and age in *M. dubia* g e r m p l a s m a n d s p a t i a l geometry study plantations. Kumar *et al.* (2024), in dry zone of Karnataka, India, reported the carbon stocks of 40.10 to 118.80 t/ha and biomass CO2 147.10 375.90 t/ha to of different *M. dubia* progenies at the age of 6 to 7- year-old plantations spaced at 5 × 5 m. The carbon stock and carbon sequestration of some progenies at the age of 5 years in the present study fall within the range reported by these workers. Singh *et al.* (2022) have also reported carbon stock of 10. 96 t/ ha and Carbon dioxide sequestration amounting to 40.17 t/ha from 2-year-old *M. dubia* which are in accordance with that provide by some progenies a n d s p a t i a l g e o m e t r y evaluations in our study. Similar individual tree range of carbon sequestration from *M. dubia* (at 5 × 4 m spacing) at different age gradation (1 to 3 years) have been reported by Choudhury *et al.* (2025).

The plantation spacing is known to influence growth and morphology of individual trees as well as quantity and quality of wood produced. Narrower spacing decrease individual growth and increase tree mortality through excessive intraspecific competition *al.,* 2024). Conversely though wider planting spacing favor diameter/girth growth, enhances stem taper substantially. Higher stem taper values tend to reduce merchantable volume of individual trees at a particular diameter at breast height. It has been reported that at stand level, volume increases with narrower planting plans to a reasonable levels (Cardoso *et al.,* 2013) and hence the biomass. The biomass production and productivity in present study has been recorded to be higher in narrower spacing/highest tree density which is in agreement with these findings.

The analysis of teak spacing studies revealed negative coordination for planting spacing, volume production, basal area and other wood characters which increase with increased plantation spacing (Perez-Cordero and Kanninen, 2003). Similarly, teak height and DBH (diameter at breast height) at age of 14 years was significantly lower in spacing of 2x2 m compared spacing regimes of 3x3 m and 4x4 m (Eliakimu *et al.,* 2015). Similar growth behavior was exhibited by *M. dubia* for present study, which might have contributed by microsite differences for height, as it is sensitive to differences in site quality. Reduced competition in wider planting spacing results in attaining higher DBH/GBH, which may be attributed to effective use of more growing space for crown and root development (Eliakimu *et al.*, 2015). The higher individual stem biomass has been reported with widest plantation spacing, which is in line with results of several other studies (Zhang *et al.,* 2013; Eliakimu *et al.,* 2015) and hence the carbon stocks and carbon sequestration was higher.

CONCLUSION

The results indicated that among 17 progenies, GJ09 produced maximum biomass and average maximum productivity, carbon stocks and carbon sequestration at the age of 5 years. Progeny GJ09 had carbon stock and carbon sequestration rate. This progeny can be further taken up for plantation programmes for higher sequestration rate. Further, there was significant variation in biomass productivity, carbon stock and carbon sequestration among individuals under different spatial geometries. At the age of 5-years, the individual tree biomass, carbon stock and carbon sequestration was maximum under 4×2 m spacing, nonetheless, owing to the maximum tree per hectare, 2×2 m spatial configuration yielded maximum biomass, carbon stocks and carbon sequestration potential. Hence, *M. dubia* has great potential for carbon sequestration.

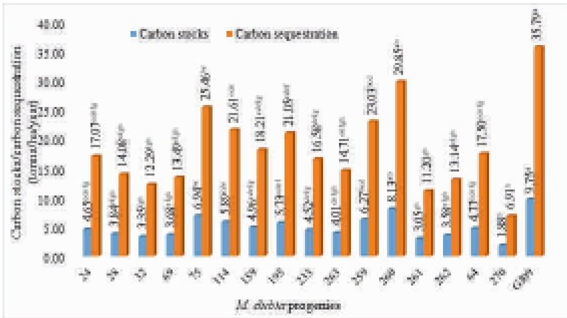

Figure 3. Variation in carbon stocks [SE(m)±0.72] and carbon sequestration [SE(m)±2.62] by M. dubia progenies in South Gujarat, means with different superscript letter in each bar indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

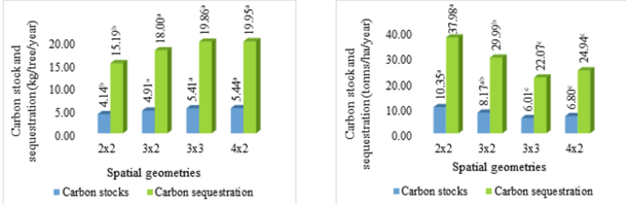

Figure 5. Variation in a) per tree carbon stock [SE(m)± 0.39] and carbon sequestration [SE(m)± 1.42] potential (kg/tree/year) and b) per hectare carbon stock [SE(m)±0.31] and carbon sequestration [SE(m)±1.12] potential of M. dubia at the age 5 years under different spatial geometries in South Gujarat, means with different superscript letter in each bar indicate significant difference (p<0.05) according to Duncan's Multiple Range Test

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