Mysore J. Agric. Sci., 60 (2) : 275-286 (2026)

Influence of *Melia dubia* Cav. on Growth and Biomass of Medicinal and Aromatic Crops under Agroforestry System

Pratiksha Patil[1], D. C. Hanumanthappa[2], M. Vimala[3], M. Mahadeva Murthy[4] and C. Nagarajaiah[5]
[1&5]Department of Forestry and Environmental Science, [3]Department of Agricultural Statistics, Applied Mathematics and Computer Science, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
[2]AICRP on Agroforestry, [4]Directorate of Research, UAS, GKVK, Bengaluru - 560 065
e-Mail : pratikshaap3@gmail.com

Authors Contribution

Pratiksha Patil:
Conduct of experiment, data collection, analysis of data and writing of original drafted manuscript

D. C. Hanumanthappa & M. Vimala:
Conceptualization, design, supervision helped in analysis of data and reviewing

M. Mahadeva Murthy & C. Nagarajaiah :
Conceptualization of the experiments and advise

Corresponding Author :
Pratiksha Patil

Received : October 2025
Accepted : November 2025

Abstract

Melia dubia-based agroforestry is beneficial for the climate, provided that appropriate species are cultivated under suitable light conditions. Agroforestry enhances the cultivation of medicinal and aromatic plants (MAPs) while simultaneously boosting ecosystem services. Employing a randomized complete block design (8 treatments × 3 replications), we examined the impact of *Melia dubia* on the growth and biomass of MAPs at Agroforestry unit, 'M' block, ZARS, GKVK , Bengaluru, India. We cultivated aromatic crops (Citronella, Lemongrass, Vetiver and Japanese mint) and medicinal herbs (kalmegh, tulsi, brahmi and peppermint) both independently and as intercrops under 5.0 m × 5.0 m spaced *Melia dubia*. We recorded growth characteristics such as height, tillers/branches, leaves, in addition to the quantities of fresh and dry herbage produced and lux readings. We employed standard allometry to determine the tree's biomass and carbon content. The *Melia dubia* canopy obstructed approximately 30-45 per cent of the light reaching the crops, hence affecting their growth performance. Brahmi, kalmegh and Japanese mint are instances of shade-tolerant or intermediate species. They exhibited enhanced leaf production and consistent fresh and dry yields beneath the canopy. Light-demanding species such as peppermint, tulsi, lemongrass, citronella and particularly vetiver resulted in reduced yields when cultivated alongside other plants. Peppermint exhibited the highest yields when cultivated in isolation. The evaluated spacing indicated that the stand possessed around 121.5 t ha^{-1} of biomass and 54.7 t ha^{-1} of carbon. Utilise brahmi, kalmegh or Japanese mint in mature or thicker stands, while reserving peppermint, tulsi and sun-loving grasses for open alleyways, broader spacings or the initial years of rotation. The findings provide pragmatic and novel guidance on integrating MAPs to optimise profitability while simultaneously producing timber and sequestering carbon.

Keywords : Agroforestry, Aromatic plant, Biomass, *Melia dubia*, Medicinal plants

India possesses a diverse array of flora utilised for medicinal and aromatic purposes. Approximately 7,500 species of these plants exist, with around 1,200 being commercially significant. The increasing worldwide demand for herbal medicines, essential oils, fragrances and cosmetics has intensified pressure on natural populations, resulting in unsustainable extraction and the depletion of valuable species. This necessitates a transition from wild plant collection to environmentally sustainable cultivation practices (Kumar *et al*., 2021 and Roy *et al*., 2019).

Agroforestry effectively addresses these issues by integrating trees with medicinal and aromatic plants (MAPs), thereby enhancing farm revenue, safeguarding biodiversity and augmenting ecosystem services such as soil fertility and carbon sequestration. It is particularly beneficial in India, where only 21.71 per cent of the land area is forested, falling short by 11.29 per cent of the requisite coverage (ISFR, 2021). Agroforestry systems simultaneously enhance tree cover and employment stability.

Malabar neem, (*Melia dubia* Cav.), is a rapidly growing tree with diverse use, increasingly favoured in agroforestry systems (Kokila *et al*., 2024). It is favoured for its wood's resistance to termites and fungi and is extensively utilised in the furniture, agriculture and plywood industries. It is an advantageous choice for agroforestry systems, as it can rapidly grow in diverse agro-climatic conditions and can be cultivated alongside other crops (Satya & Parthiban, 2018). *Melia dubia* is acknowledged not just for its timber but also for its potential to enhance nutrient and organic carbon cycling in the soil, while sequestering significant amounts of atmospheric carbon (Ananthkumar, 2011; Swamy & Puri, 2005 and Praveen Kumar *et al*., 2025).

Despite its considerable potential, limited research has been conducted on the efficacy of *Melia dubia* in conjunction with medicinal and aromatic plants. Numerous MAPs thrive in shaded conditions, allowing for their integration into *Melia* plantations without complications. This integration will enhance the system's productivity and profitability. A comprehensive evaluation of MAPs in *Melia dubia* based agroforestry systems is crucial to identify optimal crop combinations that maximise ecological and economic benefits.

The current study was conducted primarily to investigate the viability of *Melia dubia*-based agroforestry as a sustainable land-use system. The research aimed to assess the growth and production performance of medicinal and aromatic crops (MAPs) planted beneath the canopy of *Melia dubia*. The study also examined how the addition of MAP's affected the growth and biomass accumulation of *Melia dubia*, thereby analysing how the two parts of the system interacted with each other while ensuring ecological sustainability.

Material and Methods

Research Location

The field experiment was conducted in the 'M' block of the Agroforestry Unit of the Zonal Agricultural Research Station (ZARS) in (GKVK) Bengaluru, which is located in the Northern part of Bengaluru between 13° 08' North latitude and 77° 56' East longitude at an altitude of 930 m above mean sea level (MSL) and it is evaluated in three different agricultural seasons; *Rabi* (2023-24), *Summer* (2023-24) and *Kharif* (2024-25). The soil at the trial site was red sandy loam classified within the *Alfisols* group and had a moderate fertility level.

Experimental Material

The arboreal component consisted of *Melia dubia* L., which was planted in July 2017 with a spacing of 5m x 5m which were maintained according to recommended silvicultural practices, including the pruning of lateral branches and soil aeration during the *Kharif* season. Medicinal and aromatic plants (MAP's) were cultivated in the spaces between rows of *Melia dubia* in October 2023. The selected intercrops comprised lemongrass (*Cymbopogon citratus*), Citronella (*Cymbopogon nardus*), vetiver (*Vetiveria zizanioides*), Japanese mint (*Mentha arvensis*), peppermint (*Mentha piperita*), tulsi (*Ocimum sanctum*), brahmi (*Bacopa monnieri*) and kalmegh (*Andrographis paniculata*).

Experimental Design and Interventions

The research was conducted as two independent experiments employing a Randomised Complete Block Design (RCBD) with factorial concept, replicated three times. Each experiment had eight treatments, four systems for cultivating *Melia dubia* in isolation and four systems for cultivating *Melia dubia* in conjunction with other plants. The first experiment evaluated aromatic crops, comprising sole crops of lemongrass, citronella, vetiver and Japanese mint, along with their respective combinations grown beneath the canopy of *Melia dubia*. The second experiment evaluated medicinal plants, including sole crops of kalmegh, tulsi, brahmi and peppermint, long with their respective combinations within a *Melia dubia*-based agroforestry system.

Data Collection

We assessed growth parameters for the tree *viz*., height, diameter at breast height (DBH), canopy spread, basal area and volume by employing a non-destructive method during early morning hours to ascertain the above-ground biomass and utilised a root to shoot ratio of 0.26 (Ravindranath and Ostwald, 2008) to determine the below-ground biomass. The total biomass was obtained by summing the above and below-ground biomass and the carbon stock was calculated using a conversion factor of 0.45 (Pearson *et al*., 2013).

For aromatic crops, we assessed plant height, tiller count, leaf quantity, fresh and dry herbage yield. Similarly, assessed the height, branch count, leaf count, fresh and dry weight and total herbage production of medicinal plants.

A lux metre was utilised to assess light interception in both open and canopy environments, at various times (morning at 9.00 am, afternoon at 2.00 pm and evening at 5.00 pm) and readings are expressed in lux.

Statistical Analysis

Data collected were examined using analysis of variance (ANOVA). The F-test was employed to determine the significance of treatment effects at the 5 per cent probability level. For significant differences, mean separation was performed and results were expressed with the standard error of the mean (S.Em ±) and critical difference (CD) values using OPSTAT software.

RESULTS AND DISCUSSION

Growth Performance of Aromatic Crops under *Melia dubia* based Agroforestry System

The assessed *Melia dubia* based agroforestry system significantly influenced the growth characteristics of aromatic crops (Tables 1-2 and Fig. 1-2). There were distinct vegetative and yield differences between the treatments cultivated in isolation and those grown in conjunction with *Melia dubia.*

Plant Height

Among the sole cropping treatments, Vetiver (T_3) exhibited the greatest height of 147.17 cm, followed by Lemongrass (T_1) at 135.67 cm and Citronella (T_2) at 126.00 cm. Japanese mint (T_4) measured 38.14

TABLE 1

Mean growth parameters of aromatic crops at different cuttings as influenced by *Melia dubia* based agroforestry system

Treatments	Plant height (cm)	Number of tillers per plant	Number of leaves per plant
T_1 : Sole Lemongrass	135.67	124.8	57.23
T_2 : Sole Citronella	126.00	104.93	52.17
T_3 : Sole Vetiver	147.17	138.57	54.03
T_4 : Sole Japanese Mint	38.14	11.47	191.93
T_5 : Melia + Lemongrass	84.13	69.17	37.30
T_6 : Melia + Citronella	77.43	53.30	29.90
T_7 : Melia + Vetiver	56.27	21.17	15.43
T_8 : Melia + Japanese Mint	40.37	28.67	211.23
S.Em ±	3.64	2.86	3.18
CD (p=0.05)	11.02	8.68	8.65

Table 2

Fresh herbage yield (kg/ha) of aromatic crops at different cuttings as influenced by *Melia dubia* based agroforestry system

Treatments	1st Harvest	2nd Harvest	3rd Harvest
T_1 : Sole Lemongrass	1733	2133	2666
T_2 : Sole Citronella	1485	2023	2371
T_3 : Sole Vetiver	1933	2309	2797
T_4 : Sole Japanese Mint	2640	2170	1860
T_5 : Melia + Lemongrass	1200	1544	1800
T_6 : Melia + Citronella	791	972	1206
T_7 : Melia + Vetiver	343	456	515
T_8 : Melia + Japanese Mint	3212	2890	2451
S.Em ±	61.12	63.55	58.30
CD (p=0.05)	185.40	192.75	176.82

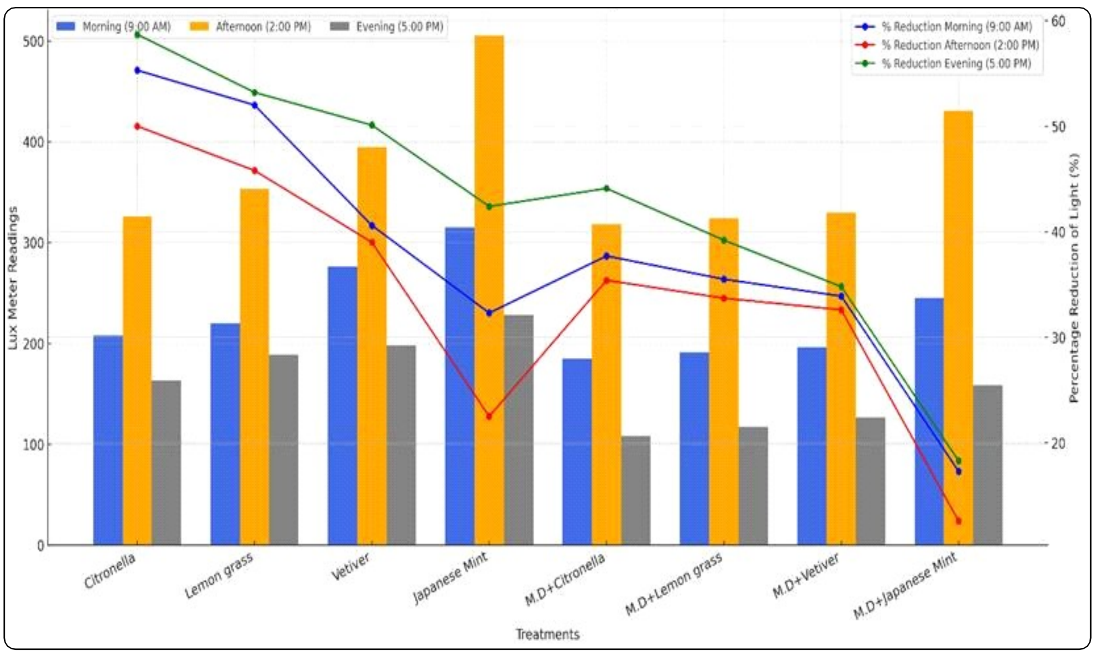

Fig. 1: LUX meter readings and percentage reduction of light interception under *Melia dubia* over open area.

centimetres, being the shortest species (Table 1). All species exhibited a marked reduction in height when cultivated beneath *Melia dubia*. The most significant decline occurred in Vetiver (56.27 cm) and Japanese mint (40.37 cm).

The canopy of *Melia dubia* intercepts a portion of the light that typically reaches the intercrops, resulting in a decrease in height. The results correspond with the findings of Joshi (2017), who observed reduced growth of aromatic grasses in Poplar-based agroforestry due to shading intensity. Similarly, Ong and Huxley (1996) showed that *Melia dubia* significantly alters the micro-environment beneath its canopy, influencing the growth of intercrops (Kulkarni, 2020).

Lemongrass and citronella, conversely, maintained a moderate height in the shade (Danata *et al*., 2022). This indicates that they can endure partial shadow and alter their form in reduced light conditions (Gupta *et al*., 2015). This adaptive response may render them suitable for application in *Melia dubia* based systems characterised by moderate canopy density.

Number of Tillers Per Plant

The quantity of tillers per plant exhibited a pattern analogous to the height of the plants (Table 1). The maximum tillers were observed in sole Vetiver (T_3) (138.57), followed by sole Lemongrass (T_1) (124.80) and lastly in sole Citronella (T_2) (104.93). The lowest of tiller number was recorded in sole Japanese mint (T_4) (11.47).

Under *Melia dubia*, tiller production significantly decreased. Melia + Vetiver (T_7) produced just 21.17 tillers, indicating that vetiver is notably sensitive to shade. The reduction in tiller quantity under shaded conditions may stem from decreased carbohydrate reserves and limited axillary bud formation, as tillering is an energy-dependent process (Ehret *et al*., 2015). Lemongrass (T_5) and citronella (T_6) demonstrated markedly elevated tiller counts (69.17 and 53.30, respectively) beneath *Melia dubia*, signifying enhanced adaptation and resource utilisation efficiency. These results align with Raj and Lal (2010), which showed that lemongrass maintains growth and tillering even in 30-40 per cent shade in agroforestry systems Mousavinik *et al*., (2016) in mint.

Number of Leaves Per Plant

The response of leaf amount per plant exhibited an inverse trend. When cultivated in isolation, Japanese mint (T_4) produced 191.93 leaves per plant. When cultivated with *Melia dubia* (T_8), it produced 211.23 leaves per plant (Table 1). This suggests that Japanese mint flourishes in moderate shade, possibly because to increased relative humidity, diminished evapotranspiration and enhanced microclimate conditions provided by tree canopy cover (Zhang *et al*., 2022). The heightened leaf proliferation compensates for the reduced plant height, indicating an adaptive morphological strategy in shade-tolerant species (Kumar *et al*., 2025).

Conversely, other fragrant plants such as lemongrass, citronella and vetiver exhibited reduced leaf production when cultivated with *Melia dubia*, aligning with their love for full sunlight. The reduction in leaf count may also result from competition for light and nutrients, which could hinder leaf growth and photosynthesis (Souvenir, 2018).

Light Interception and Lux Intensity under *Melia dubia*

The Lux metre readings recorded at various times of the day (Fig. 1) indicate significant variations in light levels between open field environments and systems utilising *Melia dubia*. The mean Lux measurements in the open field were 456.6 in the morning, 652.2 in the afternoon and 396.5 in the evening. However, under *Melia dubia* canopies, the measurements decreased to 296.5, 489.6 and 193.9 Lux, indicating that the tree canopy obstructed significant amounts of light.

Japanese mint (M.D + Japanese mint) exhibited the highest Lux values under *Melia dubia* (245.1, 430.7, and 158.2 Lux in the morning, afternoon and evening, respectively) and the minimal percentage decline in light intensity (17.3%, 12.6% and 18.3%). Conversely, citronella (M.D. + citronella) had the most significant reduction in light.

These findings indicate that *Melia dubia* modifies the microclimate by blocking incident radiation, hence reducing the direct photosynthetically active radiation (PAR) that penetrates the understory. Canopy-induced moderation can be both beneficial and limiting, intense shade hinders tillering and leaf elongation in light requiring species (*e.g.,* citronella, lemongrass), while facilitating the growth of shade-tolerant crops (*e.g.,* Japanese mint, brahmi). Whereas, Srivastav *et al*., (2024) highlighted the significant variability in shadow adaptation across medicinal and aromatic plants (MAP's). The light interception results elucidate the diminished growth and production of intercrops *viz*., medicinal and aromatic plants, such as mint and brahmi, are more suitable for cultivation alongside *Melia dubia*.

Fresh Herbage Yield

The quantity of fresh herbage (Table 2) produced shown significant variation across treatments and harvests. Vetiver (T_3) exhibited the highest yield (2797 kg ha^{-1} at the third harvest) when cultivated in isolation. Lemongrass (T_1) and citronella (T_2) were subsequently followed. Yields decreased for all species except for Japanese mint, which exhibited very high yields of 3212; 2890 and 2451 kg ha^{-1} across three distinct harvests when cultivated under *Melia dubia*.

The increased mint yield in the shade corroborates the notion that it thrives under moderate canopy cover, which reduces evapotranspiration and enhances soil water availability (Neha *et al*., 2025). Conversely, Melia + Vetiver (T_7) exhibited the lowest yield, ranging from 343 to 515 kg ha^{-1}, indicating a significant intolerance to shade. The significant treatment effects (CD @ p=0.05) confirm that yield variation is primarily due to canopy-induced light limitation and competition for underground resources (Kumar *et al*., 2024).

Dry Herbage Yield

The dry matter yield (Fig. 2) exhibited a pattern identical to that of the fresh yield. Vetiver exhibited the highest dry production among all individual crops, measuring 1297 kg ha^{-1}. Conversely, Japanese mint produced three cuttings with yields of 1608 kg ha^{-1}, 1435 kg ha^{-1} and 1226 kg ha^{-1}. This consistent performance demonstrates mint's ability to thrive in partial shade and its capacity to generate biomass through leaf expansion and increased chlorophyll retention (Neha *et al*., 2025).

Conversely, vetiver and citronella grown under *Melia dubia* demonstrated the lowest dry yields (171-247 kg ha^{-1} and 386-601 kg ha^{-1}, respectively), under scoring their requirement for light throughout growth. Reduced photosynthetic efficiency in shaded conditions and allelopathic interactions with *Melia dubia* roots may significantly impede their growth (Singh *et al*., 2023).

Growth Performance of Medicinal Crops under *Melia dubia*-based Agroforestry System

The *Melia dubia*-based agroforestry system significantly influenced the growth characteristics of

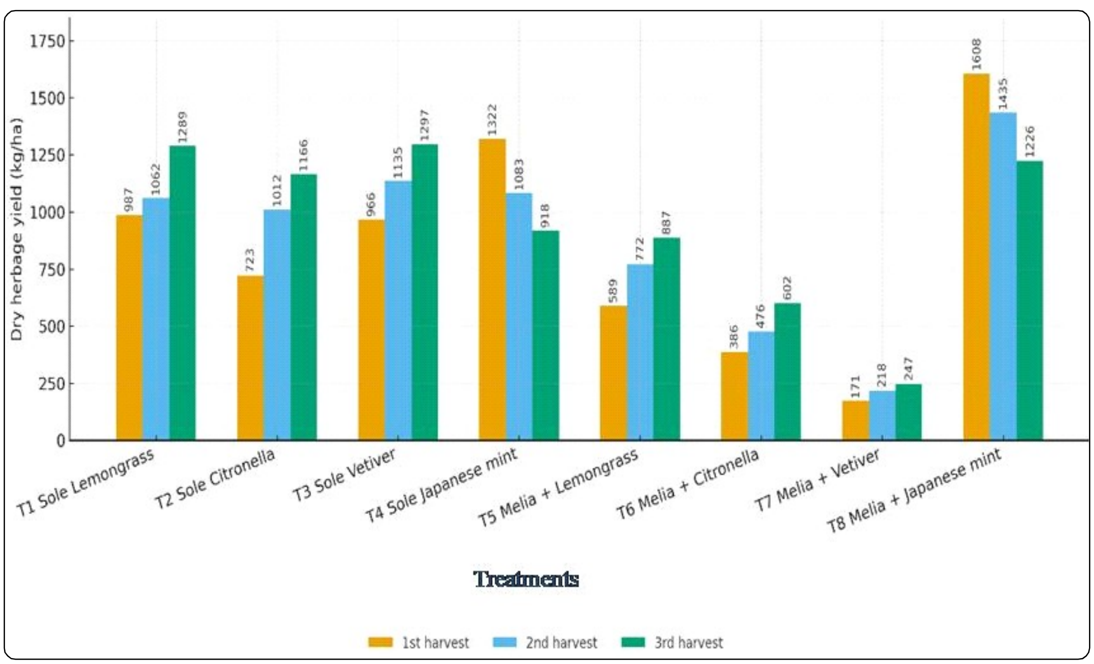

Fig. 2: Dry herbage yield (kg/ha) of aromatic crops at different cuttings as influenced by *Melia dubia* based agroforestry system

TABLE 3

Mean growth parameters of medicinal crops at different harvests as influenced by *Melia dubia* based agroforestry system

Treatments	Plant height (cm)	Number of tillers per plant	Number of leaves per plant
T_1 : Sole Kalmegh	64.80	28.23	95.83
T_2 : Sole Tulsi	56.04	8.40	150.43
T_3 : Sole Brahmi	9.17	10.20	170.40
T_4 : Sole Peppermint	52.73	33.53	237.90
T_5 : Melia + Kalmegh	70.50	40.30	221.97
T_6 : Melia + Tulsi	64.37	7.33	120.27
T_7 : Melia + Brahmi	16.67	15.17	242.33
T_8 : Melia + Peppermint	56.03	24.67	127.50
S.Em ±	1.72	0.84	6.22
CD (p=0.05)	5.21	2.54	18.86

medicinal crops (Tables 3 and Fig. 3 to 5). There were distinct vegetative and yield metrics between the treatments cultivated in isolation and those grown in conjunction with *Melia dubia* intercrops.

Plant Height

Kalmegh (T_1) exhibited the greatest height at 64.80 cm, succeeded by Tulsi (T_2) at 56.04 cm and Peppermint (T_4) at 52.73 cm. Brahmi (T_3) had the shortest height at 9.17 cm. Kalmegh (T_5) attained a height of 70.50 cm when planted beneath *Melia dubia*, indicating that the tree canopy provided beneficial shade for its growth. Brahmi (T_7) exhibited only a modest enhancement (16.67 cm), indicating that its growth is minimally affected by reduced light intensity (Table 3).

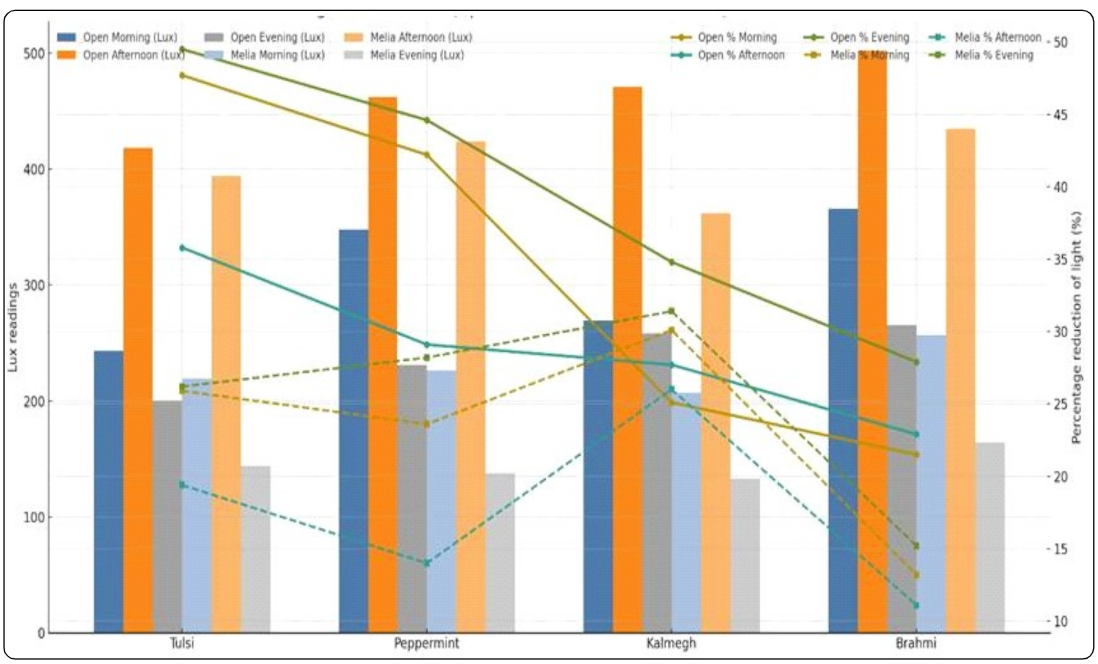

Fig. 3: LUX meter readings and percentage reduction of light interception under *Melia dubia* over open area

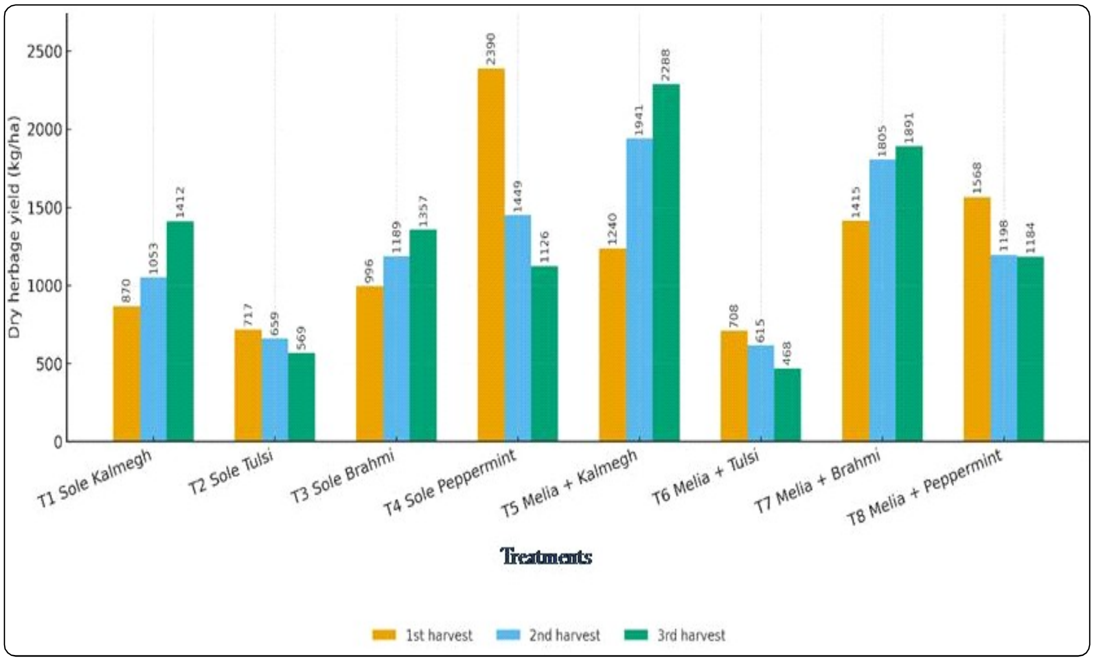

Fig. 4: Dry herbage yield (kg/ha) of medicinal plants at different cuttings as influenced by *Melia dubia* based agroforestry system

The height growth of kalmegh and tulsi plants in shaded conditions might be attributed to shade-induced elongation, a typical adaptive mechanism whereby plants lengthen their internodes to capture additional light (Kumar *et al*., 2025). The increased relative humidity and more stable microclimate beneath *Melia dubia* may have facilitated prolonged stem growth (Srivastav *et al*., 2024). Peppermint and brahmi are low-growing, spreading herbs that require full sunlight for optimal growth. They did not experience significant growth and may have even diminished in height (Bari & Rahim, 2012 and Hegde, 2018).

Number of Branches Per Plant

Various species exhibited markedly disparate quantities of branches per plant. When cultivated in isolation, peppermint (T_4) exhibited the highest number of branches (33.53), closely followed by kalmegh (28.23). Tulsi (8.40) possessed the least number of branches. Kalmegh exhibited much greater branching (40.30) when cultivated under *Melia dubia*, indicating its compatibility with arboreal systems. The combinations of Melia with brahmi and Melia with peppermint yielded 15.17 and 24.67 branches, respectively (Table 3).

The enhanced branching in *Melia dubia* and kalmegh may result from diffused radiation beneath the canopy, which optimises chlorophyll function and facilitates carbon uptake, hence promoting plant development (Hegde, 2018). The reduction in branch count for Melia + tulsi (7.33) relative to its monoculture (8.40) indicates that Tulsi necessitates greater light exposure and exhibits reduced shadow tolerance, corroborating the conclusions of Thakur *et al*. (2018) that aromatic and medicinal herbs possess fewer branches in low PAR conditions.

Number of Leaves Per Plant

The quantity of leaves on each plant, a crucial indicator of photosynthetic area, exhibited significant variation. When cultivated in isolation, peppermint (T_4) exhibits the highest leaf count (237.90), succeeded by Brahmi (170.40) and Tulsi (150.43). Melia + Brahmi (242.33) and Melia + kalmegh (221.97) exhibited the highest leaf count under *Melia dubia* (Table 3).

Brahmi's increased leaf production under the shade of a tree indicates its preference for moderate light levels, as it thrives in shaded environments and exhibits a low growth habit. In humid, partially shaded environments, brahmi often accumulates greater biomass (Smitha *et al*., 2021). Peppermint maintained high leaf counts in both light and shaded conditions, indicating partial shade tolerance, likely due to its efficient water-use physiology and high chlorophyll stability index (Barman, 2021).

Leaf count in tulsi decreased from 150.43 (sole) to 120.27 (under *Melia dubia*), indicating a preference for direct sunlight. The variation in leaf quantity among treatments indicates that light intensity is a vital determinant of canopy structure and leaf development in medicinal plants (Roy *et al*., 2019).

Light Interception and Lux Intensity under *Melia dubia*

Fig. 3, indicates that the Lux metre readings were significantly lower beneath *Melia dubia* compared to open fields. The mean Lux levels in the open field at 9:00 am, 2:00 pm and 5:00 pm were 456.6, 652.2 and 396.5 Lux, respectively. The presence of *Melia dubia* resulted in light intensity reductions to 296.5, 489.6 and 193.9 Lux, reflecting an average decrease of 30-40 per cent in light intensity. Brahmi (*Bacopa monnieri*) exhibited the greatest Lux values beneath the canopy and the lowest percentage of light attenuation (13.2-15.2%). This indicates that *Melia dubia*'s limited canopy density permits sufficient diffuse radiation for its growth. Kalmegh (*Andrographis paniculata*) exhibited the most substantial reduction in light (30-31%), followed by Tulsi (*Ocimum sanctum*) and Peppermint (*Mentha piperita*).

This pattern indicates that *Melia dubia* significantly alters the microclimatic environment, creating a gradient of light availability that influences the growth and physiological adaptability of medicinal crops. Thakur *et al*., (2018) identified analogous patterns. They stated that tree-based systems reduce direct irradiance and increase diffuse radiation, potentially benefiting understory crops that tolerate shade.

Fresh and Dry Herb Yield of Medicinal Crops under *Melia dubia* - based Agroforestry System

The treatments significantly influenced the production of both fresh and dried herbage of the therapeutic crops (Table 4 and Fig. 4). Peppermint (T_4) had the best fresh herbage output (10,882, 7,879 and 4,550 kg ha^{-1}, respectively) and the greatest dry yield (2,390, 1,449 and 1,126 kg ha^{-1}) throughout all three

Table 4

Fresh herbage yield (kg/ha) of medicinal plants at different cuttings as influenced by *Melia dubia* based agroforestry system

Treatments	1st Harvest	2nd Harvest	3rd Harvest
T_1 : Sole Kalmegh	1286	1703	2017
T_2 : Sole Tulsi	1983	1786	1477
T_3 : Sole Brahmi	1645	1745	1962
T_4 : Sole Peppermint	10882	7879	4550
T_5 : Melia + Kalmegh	1772	2591	2968
T_6 : Melia + Tulsi	1667	1573	1276
T_7 : Melia + Brahmi	2065	2370	2756
T_8 : Melia + Peppermint	7821	5903	4845
S. Em ±	113.6	158.0	84.8
CD (p=0.05)	344.6	479.5	257.3

harvests. The superior performance of peppermint under isolated conditions can be attributed to its elevated photosynthetic rate, vigourous vegetative development and effective canopy architecture in full sunlight (Praveen Kumar *et al*., 2025).

Kalmegh (T_1) and Brahmi (T_3) had moderate yields when cultivated independently, although Tulsi (T_2) demonstrated inferior yields, particularly after the third harvest. The decline in Tulsi yield in successive harvests is due to the exhaustion of stored assimilates and the plant's heightened light demands, as supported by Satya and Parthiban (2018), who noted reduced biomass of *Ocimum sanctum* in shaded or diffused light conditions.

Yield patterns exhibited significant variability when *Melia dubia* was utilised. Brahmi (T_7 : Melia + Brahmi) and Kalmegh (T_5 : Melia + Kalmegh) demonstrated the greatest fresh and dry herbage yields among all the intercrops. This indicates they excelled in partly shade conditions. Brahmi yielded 2,065 kg ha^{-1} in the first harvest, 2,370 kg ha^{-1} in the second and 2,756 kg ha^{-1} in the third for fresh yield, and 1,415 kg ha^{-1} in the first, 1,805 kg ha^{-1} in the second and 1,891 kg ha^{-1} in the third for dry output. Melia + Kalmegh yielded between 1,772 and 2,968 kg ha^{-1} of fresh biomass and between 1,240 and 2,288 kg ha^{-1} of dry biomass.

This pattern aligns with the physiological processes of their bodies when in the shade. *Bacopa monnieri* and *Adrographis paniculata* demonstrate maximum performance with a 35-45 per cent reduction in light, efficiently utilising diffuse radiation and maintaining high levels of chlorophyll b (Rajamani *et al*., 2019). The unassuming canopy of *Melia dubia* likely enhanced the microclimate for biomass growth by reducing leaf temperature, minimising water evaporation and increasing relative humidity (Swamy & Puri, 2005; Roy *et al*., 2019 and Kulkarni, 2020).

The *Melia dubia* based agroforestry system created a microclimate beneath the canopy that received approximately 30-45 per cent less light than open fields. This exerted diverse impacts on medicinal and aromatic plant species. Shade-tolerant and intermediate species, including brahmi and kalmegh among medicinal crops and Japanese mint among aromatic crops, yielded greater leaf production and consistent outputs of fresh and dried herbage beneath the canopy. This indicates their effective use of diffuse radiation. Light-demanding species such as Peppermint, Tulsi, Lemongrass, Citronella and particularly Vetiver exhibited significantly reduced yields when cultivated in conjunction, with Vetiver performing optimally under solitary conditions. Intercropping did not adversely impact tree performance; *Melia* stands yielded around 121.5 t ha^{-1} total biomass and roughly 54.7 t C ha^{-1} carbon stock, which remained unaffected by MAP's when *Melia* planted at 5×5 m spacing. The results indicate that *Melia* agroforestry is an effective environmental system when appropriate crops are cultivated in suitable locations. Brahmi, Kalmegh and Japanese mint are better suited for cultivation in mature or densely populated stands, whereas Peppermint, Tulsi and sun-loving grasses should be planted in open alleyways, with greater spacing or during early rotation years. Light regulation can be achieved through periodic pruning or thinning of *Melia dubia*. The alignment of species with light conditions can enhance farmers' profitability while promoting the growth of trees and carbon sequestration.

Acknowledgement : The authors are grateful to AICRP on Agroforestry, UAS, GKVK, Bengaluru and also highly thankful to CAFRI, Jhansi for kind support of land and finance, respectively.

References

Ananthkumar, M. A., 2011, Soil properties and dynamics of major nutrients in soils as influenced by shade trees, rainfall pattern and nutrient management in coffee growing areas of Karnataka. *Mysore J. Agric. Sci.,* **45** (3) : 45 - 58.

Bari, M. S. and Rahim, M. A., 2012, Economic evaluation and yield performance of some medicinal plants in coconut based multi-storeyed agroforestry systems. *The Agriculturists*, **10** (1) : 71 - 80.

BARMAN, B. R., 2021, Indoor performance of pepper mint (*Mentha piperita* L.) in response to vermicompost and light quality.

DANATA, N. H., AINI, N., UDAYANA, C., SETIAWAN, A. AND KURNIANINGRUM, F., 2022, Growth, yield and respiration rate of *Cymbopogon nardus* L. at different shade levels. In *International Conference on Agricultural, Nutraceutical and Food Science (ICANFS),* **1** : 150 - 155.

EHRET, M., GRAB, R. AND WACHENDORF, M., 2015, The effect of shade and shade material on white clover/ perennial ryegrass mixtures for temperate agroforestry systems. *Agroforestry systems*, **89** (3) : 557 - 570.

GUPTA, P., DHAWAN, S. S. AND LAL, R. K., 2015, Adaptability and stability based differentiation and selection in aromatic grasses (*Cymbopogon* species) germplasm. *Industrial Crops and Products*, **78** : 1 - 8.

HEGDE, R., 2018, Silviculture techniques to boost medicinal and aromatic trees. *Conservation and Utilization of Plant Genetic Resources in Medicinal and Aromatic Crops*, pp. : 121.

INDIA STATE OF FOREST REPORT, 2021, Forest survey of India, Ministry of Environment, Forest and Climate Change, Government of India. ISBN : 978-81-950073-1-8 (https://fsi.nic.in/forest-report-2021-details).

JOSHI, K., 2017, Performance of different Mentha species under poplar-based agroforestry system (Doctoral dissertation, GB Pant University of Agriculture and Technology, Pantnagar - 263145 (Uttarakhand), pp. : 164.

KOKILA, A., NAGARAJAIAH, C. AND HANUMANTHAPPA, D. C., 2024, Accumulation and decomposition of litter in different agroforestry systems under semiarid condition. *Mysore J. Agric. Sci.*, **58** (4) : 12 - 20.

KULKARNI, S., 2020, Agronomic manipulations for productivity and income enhancement in *Melia dubia* Cav.based agroforestry system under organic production. *Journal of Environmental Management*, **6** (12) : 12 - 18.

KUMAR, B. M., KUNHAMU, T. K., BHARDWAJ, A. AND SANTHOSHKUMAR, A. V., 2024, Subcanopy light availability, crop yields and managerial implications: a systematic review of the shaded cropping systems in the tropics. *Agroforestry Systems*, **98** (8) : 2785 - 2810.

PRAVEEN KUMAR, M., RINKU VERMA., HANUMANTHAPPA, D. C., MAHADEVA MURTHY, M., MADAPPA, S., RAO, G. G. E. AND YOGESH, T., 2025. Influence of *Melia dubia* on growth and biomass of fodder grasses. *Mysore J. Agric. Sci*, **59** (1) : 244 - 255.

MOUSAVINIK, S. M., ASGHARIPOUR, M. R. AND SARDASHTI, S., 2016, Manure and light intensity affect growth characteristics and essential oil of peppermint (Mentha piperita L.). *Journal of Essential Oil Bearing Plants*, **19** (8) : 2029 - 2036.

NEHA, T., SIVARAM, G. T. AND YUVARAJ, K. M., 2025, Evaluation of promising species of mint in terms of growth, herbage and oil yield under open and shade net conditions. *International Journal of Advanced Biochemistry Research,* **8** (9) : 1021 - 1025.

ONG, C. K. AND HUXLEY, P. (EDS.), 1996, *Tree-crop interactions: a physiological approach*, pp. : 386.

PEARSON, T., WALKER, S. AND BROWN, S., 2013, *Sourcebook for land use, land-use change and forestry projects*. World Bank, Washington, DC, pp. : 192.

RAJ, A. J. AND LAL, S. B., 2010, Compatibility of lemon grass (*Cymbopogon flexuous*) as aromatic intercrop under teak (*Tectona grandis*) based agroforestry system. *Journal of Tropical Forestry*, **26** (1) : 21 - 25.

RAJAMANI, K., NALINA, L. AND HEGDE, L., 2019, Medicinal and aromatic crops. *AgriMoon*, pp. : 1 - 195.

RAVINDRANATH, N. H. AND OSTWALD, M., 2008, Carbon inventory methods handbook for greenhouse gas inventory, carbon mitigation and round wood production projects. Dordrecht: Springer Nether lands. pp. : 256 - 262.

ROY, A. K., AGRAWAL, R. K., BHARDWAJ, N. R., MISHRA, A. K. AND MAHANTA, S. K., 2019, Indian fodder scenario: Redefining state wise status. *All India Coordinated Research Project on Forage Crops and Utilization, Jhansi* - **284** (3) : 1 - 201.

Sathya, M. and Parthiban, K.T., 2018, Growth performance, variability and heritability studies in *Melia dubia* Cav. *Life sciences leaflets*, **102** : 12 - 18.

Singh, N., Yadav, H. K. and Yadav, S. K., 2023, Advances in Medicinal and Aromatic Crop Production Technologies. In *Advances in Crop Production and Climate Change*, CRC Press. pp. : 239 - 266.

Smitha, G. R., Kalaivanan, D. and Sujatha, S., 2021, Influence of shade and organic nutrition on growth, yield and quality of memory enhancing herb, Brahmi (*Bacopa monnieri* L.). *Med. Plants-Int. J. Phytomed. Relat. Ind*., **13** (1) : 72 - 90.

Souvenir, A. A., 2018, Expo-2018 held from 17th to 18th March, 2018 at College of Horticulture and Forestry, *Central Agricultural University, Pasighat, Arunachal Pradesh*. pp. : 182.

Srivastav, A., Kumar, D. and Barman, P. K., 2024, Research article suitability of *Melia dubia* based agroforestry in Eastern Uttar Pradesh, India. pp. : 162.

Swamy, S. L. and Puri, S., 2005, Biomass production and C-sequestration of *Gmelina arborea* in plantation and agroforestry system in India. *Agroforestry systems*, **64** (3) : 181 - 195.

Thakur, N. S., Jilariya, D. J., Gunaga, R. P. and Singh, S., 2018, Positive allelospoly of *Melia dubia* Cav. spatial geometry improve quantitative and qualitative attributes of Aloe vera L. *Industrial Crops and Products*, **119** : 162 - 171.

Zhang, W., Xie, H., Han, S. A., Wang, M., Pan, M. Q., Qiao, X. and Li, L., 2022, Effect of tree form on wheat yield via changing microenvironment in almond - wheat intercropping. *Agroforestry Systems*, **96** (2) : 387 - 406.