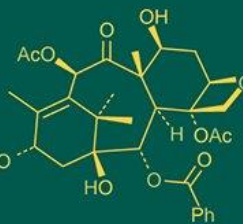
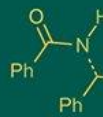
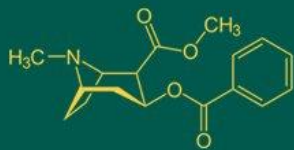


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Comparative profitability of aromatic and medicinal crops in *Melia dubia* cav-based agroforestry systems

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Abstract

The study evaluated the economic performance of four aromatic and medicinal crops in both monoculture and *Melia dubia*-based agroforestry system. The experiment was conducted at agroforestry unit, ZARS, GKVK, Bengaluru, employing a split plot design with eight cropping treatments and two clones of *Melia dubia*. We examined economic aspects like the cost of crop cultivation, gross returns, net returns, and the benefit-cost (B:C) ratio. Lemongrass and Japanese mint are the most advantageous fragrant crops performed better in agroforestry systems. They exhibited superior net returns (₹94,004 and ₹93,640 ha⁻¹) and benefit-cost ratios (2.22 and 2.21, respectively) compared to solitary cultivation. Conversely, citronella performed poorly in shaded conditions (B:C ratio of 0.36), indicating its aversion to shade. Vetiver generated reduced revenue due to its roots competing with other flora and its poor adaptation to low light conditions. Kalmegh and Brahmi emerged as the most lucrative medicinal crops for agroforestry, yielding net returns of ₹86,612 and ₹83,564 per hectare, respectively. Nonetheless, tulsi and peppermint performed better in open conditions than in *Melia dubia*, which exhibited reduced yields due to its higher light requirements. The research indicates that selecting crops based on their shade tolerance and resource use is crucial for optimizing the profitability of agroforestry systems. Agroforestry systems using *Melia dubia* can significantly enhance farm profitability when integrated with compatible aromatic and medicinal plants.

Keywords: Aromatic crops, benefit-cost ratio, intercropping, kalmegh, lemongrass, *Melia dubia*, medicinal plants

Introduction

Agroforestry is acknowledged as a sustainable land-use strategy that combines trees with crops and/or livestock to improve production, profitability, and ecological resilience. It enhances soil fertility, optimizes nutrient cycling, and improves microclimatic control, therefore tackling critical issues such as land degradation, climate variability, and diminishing agricultural revenue in tropical and subtropical countries (Nair, 1993; Jose, 2009) [7, 17].

Melia dubia (Malabar neem) has garnered significant interest among fast-growing tree species due to its swift growth, substantial biomass yield, and applicability in the timber and pulp sectors. Its adaptability to various agro-climatic conditions and compatibility with agricultural crops render it a desirable element in agroforestry systems (Deshmukh *et al.*, 2025; Singh, 2019) [5, 25]. The deciduous characteristics and comparatively open canopy of *Melia dubia* alters the microenvironment by affecting light availability, temperature, and soil moisture, hence altering the development and productivity of intercropped species (Srivastva, 2023; Kulkarni, 2020) [9, 27].

The incorporation of high-value aromatic and medicinal crops into agroforestry systems presents considerable opportunities for revenue diversification and increased farm profitability. Aromatic crops viz., lemongrass, citronella, vetiver, and Japanese mint are significant due to their essential oil content, which is extensively utilized in the pharmaceutical, cosmetic, and food sectors. Medicinal herbs such as tulsi, kalmegh, brahmi, and peppermint are esteemed for their therapeutic attributes and rising global demand (Singh *et al.*, 2012; Pathak and Bharati, 2018; Panghal *et al.*, 2010) [19, 20]. The efficacy of intercrops in agroforestry systems is primarily determined by their physiological and ecological adaptation to changed environmental circumstances (Rao *et al.*, 2007; Murthy *et al.*, 2016) [15, 22]. Tree

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Canopies diminish solar radiation, regulate temperature, and enhance soil moisture, thereby benefiting shade-tolerant plants while negatively impacting light-demanding crops by restricting photosynthesis and biomass accumulation (Kumar *et al.*, 2024; Cunha *et al.*, 2025)^[3, 10]. Essential oil crops demonstrate heterogeneity in productivity and composition across varying light conditions, rendering crop selection a critical element in agroforestry design.

Prior research indicates that fragrant grasses like lemongrass, may maintain productivity in partial shadow, while crops such as citronella and peppermint exhibit more sensitivity to diminished light conditions (Kumari *et al.*, 2025; Adhikary *et al.*, 2026)^[1, 11]. Medicinal herbs like brahmi and kalmegh thrive under mild shade, however tulsi typically need more light intensity for optimum growth and metabolite synthesis (Nair and Groot, 2021; Pandey, 2025)^[16, 18].

Aside these insights, there is a paucity of knowledge about the comparative economic performance of aromatic and medicinal crops within *Melia dubia*-based agroforestry systems. Therefore, this study aims to assess the economic viability of specific aromatic and medicinal crops in both monoculture and agroforestry settings, with the goal of selecting appropriate and economically sustainable intercrops for enduring agroforestry systems.

Materials and Methods

Experimental site and location

The study entitled “Performance of medicinal and aromatic crops under *Melia dubia*-based agroforestry system” was conducted at the ‘M’ block of the All India Coordinated Research Project (AICRP) on Agroforestry, Zonal Agricultural Research Station (ZARS), Gandhi Krishi Vigyan Kendra (GKVK), University of Agricultural Sciences, Bangalore, Karnataka, India, from January 2024 to March 2025. The experimental site is located at a latitude of 13°08' N and a longitude of 77°56' E, with an elevation of 930 m above mean sea level. The region is situated in Karnataka's Eastern Dry Zone, characterized by a semi-arid environment with distinct dry and wet seasons.

Soil characteristics

The experimental site features red sandy loam soil classified as *Alfisol*. The first soil analysis indicated that the soil exhibited mild acidity, with a pH range of 5.34 in the open field to 5.42 beneath *Melia dubia*. The concentration of organic carbon ranged from 0.38 to 0.45%, whereas the available quantities of nitrogen, phosphorus, and potassium were between 239.53 and 258.16 kg ha⁻¹, 20.05 and 21.68 kg ha⁻¹, and 201.29 and 208.68 kg ha⁻¹, respectively.

Experimental design

The experiment was conducted using a split plot design (SPD) with three replications. The main plots consisted two clones of *Melia dubia* (MTP-1 and MTP-2), whereas the subplot treatments involved four aromatic and four medicinal crop combinations. In July 2017, the trees were planted at an interval of 5 metres. Medicinal and aromatic crops were intercropped in October 2023. The study was conducted in an experimental area of 900 m² during the *rabi*/summer 2023–24 and *kharif* 2024–25 seasons.

Treatment details

Aromatic crop treatments: The experiment on aromatic

crops comprised eight treatments involving both monocropping and intercropping systems with *Melia dubia*. The treatments were as follows:

- T₁: Sole lemongrass (*Cymbopogon citratus*)
- T₂: Sole vetiver (*Chrysopogon zizanioides*)
- T₃: Sole citronella (*Cymbopogon nardus*)
- T₄: Sole Japanese mint (*Mentha arvensis*)
- T₅: *Melia dubia* + lemongrass
- T₆: *Melia dubia* + vetiver
- T₇: *Melia dubia* + citronella
- T₈: *Melia dubia* + Japanese mint

The sole cropping treatments (T₁–T₄) were maintained under open field conditions, whereas intercropping treatments (T₅–T₈) were established under the canopy of *Melia dubia* trees to evaluate the effect of tree-crop interactions on growth, yield, and economic performance of aromatic crops.

Medicinal crop treatments

Similarly, the medicinal crop experiment consisted of eight treatments involving sole and intercropping systems with *Melia dubia*. The treatments were:

- T₁: Sole tulsi (*Ocimum sanctum*)
- T₂: Sole brahmi (*Bacopa monnieri*)
- T₃: Sole kalmegh (*Andrographis paniculata*)
- T₄: Sole peppermint (*Mentha piperita*)
- T₅: *Melia dubia* + tulsi
- T₆: *Melia dubia* + brahmi
- T₇: *Melia dubia* + kalmegh
- T₈: *Melia dubia* + peppermint

In this experiment, treatments T₁–T₄ were grown as monocrops under open conditions, while treatments T₅–T₈ were cultivated as intercrops beneath the *Melia dubia* canopy. This setup enabled the assessment of species-specific responses to shade, resource competition, and microclimatic variations within the agroforestry system.

Crop management

All crops were cultivated following recommended agronomic practices, i.e., appropriate spacing, fertilization, irrigation, and intercultural operations. Essential oils were extracted through hydro-distillation using a Clevenger apparatus.

Economic analysis

The economic feasibility of different treatments was evaluated using standard cost–return analysis. The major economic parameters considered were cost of cultivation, gross returns, net returns, and benefit–cost (B:C) ratio.

Cost of cultivation

The cost of cultivation was calculated by considering all input and operational costs involved in crop production. These included expenses on planting materials, fertilizers, farmyard manure, irrigation, plant protection chemicals, and labor charges for various field operations such as land preparation, planting, weeding, and harvesting. All costs were calculated based on the prevailing market rates during the experimental period and expressed in Indian Rupees per hectare (₹ ha⁻¹).

Cost of Cultivation (₹ ha^{-1})
 $= \sum(\text{Cost of all inputs} + \text{Labour} + \text{Miscellaneous expenses})$

Gross returns

Gross returns represent the total income generated from the produce without deducting the cost of cultivation. It was calculated based on the total yield (herbage and/or essential oil) and the prevailing market price.

Gross Returns (₹ ha^{-1})
 $= \text{Total Yield (kg ha}^{-1})$
 $\times \text{Market Price (₹ kg}^{-1})$

Net returns

Net returns indicate the actual profit obtained after deducting the cost of cultivation from the gross returns. This parameter provides a direct measure of economic profitability.

Net Returns (₹ ha^{-1}) = Gross Returns – Cost of Cultivation

Benefit–Cost Ratio (B:C Ratio)

The benefit–cost ratio is used to evaluate the economic efficiency of each treatment. It represents the returns obtained per unit cost invested.

$$\text{B:C Ratio} = \frac{\text{Net Returns (₹ ha}^{-1})}{\text{Cost of Cultivation (₹ ha}^{-1})}$$

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate to the split plot design using OPSTAT software. Treatment means were compared at a 5% level of significance (Steel and Torrie, 1960).

Results

Economics of aromatic crops as influenced by *Melia dubia* clones in agroforestry system

The economic performance of aromatic crops cultivated in monoculture and *Melia dubia*-based agroforestry systems exhibited disparities in cultivation costs, gross returns, net returns, and benefit–cost (B:C) ratios.

Citronella had the lowest cost of cultivation among sole cropping systems (₹60,916 ha^{-1}), whereas vetiver had the highest cost (₹95,031 ha^{-1}). This was mostly because vetiver needed more manpower and planting materials. The gross returns for citronella was ₹88,050 ha^{-1} and for vetiver was ₹134,000 ha^{-1} . Net returns followed a similar pattern, with citronella gave net returns of ₹27,134 ha^{-1} and vetiver ₹38,969 ha^{-1} . Lemongrass and Japanese mint followed next, with net returns of ₹34,954 ha^{-1} and ₹36,640 ha^{-1} , with B:C ratios of 1.56 and 1.58, respectively.

On the other hand, combining *Melia dubia* with aromatic crops made more profitable. *M. dubia* + lemongrass system had the best economic results, with gross returns of ₹170,800 ha^{-1} , net returns of ₹94,004 ha^{-1} , and a B:C ratio of 2.22. *M. dubia* and Japanese mint also made a gross profit of ₹171,000 ha^{-1} and a net profit of ₹93,640 ha^{-1} , with a B:C ratio of 2.21. These results showed that these crops can work well with agroforestry systems. This is probably because they have shallow root systems, can handle mild shade, and can respond to changes in microclimatic conditions.

On the other hand, citronella did not do well under *Melia dubia*, with the lowest gross returns (₹80,137 ha^{-1}), net returns (₹21,221 ha^{-1}), and B:C ratio (0.36). The decrease is due to its susceptibility to shadow, which hinders the production of biomass and essential oils. Vetiver also had lower profitability (net return ₹15,219 ha^{-1} ; B:C ratio 1.14), perhaps because its roots were competing with other plants and it wasn't growing as well in low light.

In general, the results show that agroforestry systems that use *Melia dubia* may greatly improve economic returns when fragrant crops that go well with it, such lemongrass and Japanese mint, are used. Shade tolerance and how the roots of different plants interact have a big effect on how well crops grow. This shows how important it is to choose the right species when designing agroforestry.

Table 1: Economics of aromatic crops as influenced by *Melia dubia* clones in agroforestry system

Treatment	Gross return (Rs ha ⁻¹)	Cost of cultivation (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B:C ration
T1: Sole Lemon grass	97800	62846	34954	1.56
T2: Sole Citronella	88050	60916	27134	1.45
T3: Sole Vetiver	134000	95031	38969	1.41
T4: Sole Japanese mint	100050	63410	36640	1.58
T5: <i>M. dubia</i> + Lemongrass	170800	76796	94004	2.22
T6: <i>M. dubia</i> + Citronella	80137	58916	21221	0.36
T7: <i>M. dubia</i> + Vetiver	124200	108981	15219	1.14
T8: <i>M. dubia</i> + Japanese mint	171000	77360	93640	2.21

Economics of medicinal crops as influenced by *Melia dubia* based agroforestry system

The economic evaluation of medicinal crops under monoculture and agroforestry systems also revealed substantial variation in profitability. Among sole crops, tulsi recorded the lowest cultivation cost (₹43,880 ha^{-1}), followed by kalmegh (₹48,495 ha^{-1}) and brahmi (₹48,743 ha^{-1}), while peppermint had the highest cost (₹56,743 ha^{-1}).

In terms of returns, tulsi generated the highest net return (₹61,040 ha^{-1}) and B:C ratio (2.39), followed by peppermint (₹59,927 ha^{-1}), brahmi (₹58,297 ha^{-1}), and kalmegh (₹51,625 ha^{-1}). These results indicate that all medicinal crops are economically viable under open field conditions.

Under agroforestry conditions, certain crops exhibited enhanced performance. The *M. dubia* + kalmegh system recorded the highest net return (₹86,612 ha^{-1}) with a B:C ratio of 2.39, followed by *M. dubia* + brahmi (₹83,564 ha^{-1} ; B:C ratio 2.33). The improved performance of these crops can be attributed to their moderate shade tolerance, efficient nutrient utilization, and improved soil moisture conditions under tree canopy.

However, tulsi and peppermint performed poorly when integrated with *Melia dubia*. Net returns declined to ₹34,927 ha^{-1} for tulsi and ₹22,794 ha^{-1} for peppermint, with B:C ratios of 1.60 and 1.32, respectively. These reductions are likely due to the adverse effects of partial shading on biomass accumulation and essential oil production.

The findings demonstrate that the success of medicinal crops in agroforestry systems depends largely on species-specific responses to shade. Kalmegh and brahmi emerged as the most suitable intercrops, while tulsi and peppermint are better suited for open cultivation.

Table 2: Economics of medicinal crops as influenced by *Melia dubia* clones in agroforestry system

Treatment	Gross return (Rs ha ⁻¹)	Cost of cultivation (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B:C ratio
T ₁ : Sole Kalmegh	100120	48495	51625	2.06
T ₂ : Sole Tulsi	104920	43880	61040	2.39
T ₃ : Sole Brahmi	107040	48743	58297	2.20
T ₄ : Sole Peppermint	116670	56743	59927	2.06
T ₅ : <i>M. dubia</i> + Kalmegh	149057	62445	86612	2.39
T ₆ : <i>M. dubia</i> + Tulsi	92757	57830	34927	1.60
T ₇ : <i>M. dubia</i> + Brahmi	146258	62693	83564	2.33
T ₈ : <i>M. dubia</i> + Peppermint	93488	70693	22794	1.32

Discussion

This study demonstrates that the economic viability of aromatic and medicinal crops is significantly influenced by their compatibility with *Melia dubia*-based agroforestry systems, particularly for shade tolerance, root interactions, and resource use efficiency.

Economics of aromatic crops

Lemongrass and Japanese mint demonstrate greater profitability in agroforestry systems compared to monoculture, indicating their adaptability to partial shade and fluctuating microclimates. The cultivation of these crops in conjunction with *Melia dubia* yielded significantly higher net returns and benefit-cost ratios, indicating a synergistic relationship between the tree and the crops. This may be attributed to their superficial root systems, which facilitate competition with other plants subterraneously, and their ability to continuously generate biomass and essential oils despite limited light availability. Dagar *et al.* (2023)^[4] have recorded analogous findings, indicating that aromatic grasses flourish in agroforestry systems due to enhanced microclimatic conditions, such as increased soil moisture and reduced temperatures. Hubert-Schöler *et al.* (2024)^[6] stated that many essential oil crops may continue to yield even under partial shading, without significant loss in output.

Conversely, citronella's low benefit-to-cost ratio (0.36) indicated a significant decline in economic returns when cultivated in an agroforestry system. This indicates a significant sensitivity to shadow, adversely affecting photosynthesis, biomass growth, and the synthesis of essential oils. Kakaraparthi *et al.* (2014)^[8] discovered that citronella yields and oil content diminished in shaded environments, indicating its requirement for full sunlight for optimal growth. Vetiver exhibited decreased earnings when cultivated alongside *Melia dubia*, likely due to intense root competition and its incapacity to adapt to low-light conditions. This aligns with the findings of Maitra *et al.*

(2024)^[13], which indicated that vetiver's tillering and root biomass diminished under tree canopies.

The results indicate that aromatic crops may only prosper in agroforestry systems if they adapt to the environment, particularly by tolerating shade and optimizing resource utilization amidst competition from trees and other crops.

Economics of medicinal plants

The economic analysis of medicinal crops revealed a same trend, indicating significant disparities in crop performance between monoculture and agroforestry systems. Tulsi and peppermint had superior net returns and benefit-cost ratios when cultivated in open areas, indicating their preference for full sunlight and optimal growing conditions. However, their performance diminished when cultivated under *Melia dubia*, indicating a sensitivity to reduced light conditions. Studies by Singla *et al.* (2022)^[26] and Saran *et al.* (2021) demonstrate that tulsi displays reduced leaf biomass and secondary metabolite production under shadowed conditions. Mousavinik *et al.* (2016)^[14] said that peppermint requires ample light to produce optimal menthol, and that shading diminishes both its yield and oil quality.

Kalmegh and Brahmi demonstrated superior economic returns when cultivated alongside trees, indicating their potential efficacy as intercrops in systems utilizing *Melia dubia*. Their improved performance can be attributed to moderate shade tolerance, efficient nutrient absorption, and optimal utilization of soil moisture held under tree canopies. The findings correspond with previous studies by Ram *et al.* (2025)^[21], Liphon & Detpiratmongkol (2017), and Barazetti *et al.* (2022)^[2], which shown that some medicinal plants flourish in partial shade due to improved microclimatic conditions and reduced evapotranspiration.

Conclusion

Research indicates that agroforestry systems with *Melia dubia* can significantly enhance farm profitability when appropriate intercrops are used. In agroforestry settings, fragrant crops such as lemongrass and Japanese mint, together with medicinal crops like kalmegh and brahmi, generated higher profits due to their ability to thrive in shaded conditions and utilize resources more effectively. Conversely, monocropping proved more effective for shade-intolerant crops such as citronella, tulsi, and peppermint. Selecting appropriate crops that align with the ecosystem is crucial for optimizing productivity and cost-efficiency in agroforestry systems.

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