E-ISSN: 2618-0618
P-ISSN: 2618-060X
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www.agronomyjournals.com
2024; 7(12): 314-320
Received: 18-11-2024
Accepted: 09-12-2024

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Comparative growth and yield analysis of lemongrass varieties under mangium-based agroforestry system in central Chhattisgarh

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i12d.2152

Abstract
The present investigation was conducted at Indira Gandhi Krishi Vishwavidyalaya, Raipur, India, during the 2022-23 and 2023-24 growing seasons, to study the growth, yield, and essential oil production of lemongrass varieties grown in a 24-year-old Mangium-based agroforestry system. Significant genotypic differences were observed in growth parameters, including plant height, tiller count, plant spread, and Leaf Area Index (LAI). T_1-Krishna recorded the highest plant height (157.20 cm), while T_4-Neema excelled in tiller production (65.53) and plant spread (75.52 cm). The highest LAI values were observed in T_2-CG-1 (40.10) and T_7-Praman (38.47), indicating superior light capture and photosynthetic efficiency, whereas T_8-Kalam and T_6-CKP-25 showed reduced growth performance under shaded conditions. Yield parameters also varied significantly, with T_4-Neema achieving the highest fresh (131.01 q/ha) and dry biomass yields (36.03 q/ha) and T_1-Krishna recording the highest essential oil content (0.75%) and oil yield (91.97 l/ha). T_7-Praman also performed well in oil yield (91.25 l/ha), whereas T_6-CKP-25 exhibited the lowest biomass and oil yields. These findings underscore the importance of varietal selection in optimizing lemongrass cultivation for both growth and yield, with T_4-Neema and T_1-Krishna identified as promising varieties for biomass and oil production, respectively, under shaded agroforestry systems.

Keywords: Lemongrass, agroforestry, *Acacia mangium*, essential oil, growth performance, biomass production, partial shading, randomized block design (RBD), sustainable cultivation.

Introduction
India, being the most populated country in the world, consists of about 17 per cent world's human population and 15 per cent of livestock population supported only on 2.4 per cent geographical area, which is very bleak to support such a huge population. Since, land holdings are shrinking due to population growth, there is a tremendous pressure on the earth's finite natural resources to meet the demands of an expanding population. There is a need for integrated systems like agroforestry because there is no room for horizontal land expansion. Sustainability in agricultural production systems along with the food and nutritional security are major challenges due to climate change, increasing population pressure and over exploitation of natural resources (Castle *et al.*, 2022, Silva *et al.*, 2022) [6, 33]. Agroforestry systems offer a viable solution by integrating trees and crops to optimize the positive interactions between components, enhancing productivity, biodiversity, and resilience (Dutta *et al.*, 2023) [11].
Acacia mangium willd, a fast-growing evergreen tree from the Fabaceae family, is a significant species within the *Acacia* genus, which comprises over 1,200 species (Maslin, 1995) [25]. Native to the humid tropical forests of northeastern Australia, Papua New Guinea, and Indonesia, *A. mangium* thrives in low-elevation, well-drained acidic soils (National Research Council, 1983) [27]. Since its introduction to Southeast Asia in the 1960s, it has been widely planted across tropical regions due to its adaptability and economic value (Pinyopusarerk *et al.*, 1993) [30]. Growing up to 30 meters tall, *Acacia mangium* is used for pulp, paper, timber, and fuel. Its nitrogen-fixing ability and rapid growth make it ideal for reforestation and agroforestry systems. The tree's wood, with a calorific value of 4,800-4,900 Kcal/kg, is versatile, while its sawdust is used for mushroom cultivation, and leaves provide forage for livestock (Lemmens *et al.*, 1995) [23].

Cymbopogon flexuosus L., commonly known as lemongrass, is a perennial tropical grass from the Poaceae family, known for its essential oil with a fresh citrus fragrance. Native to India, Pakistan, and Sri Lanka, lemongrass is now cultivated across tropical and subtropical regions of Asia, Africa, and South America (Manzoor *et al.*, 2013) [24]. The global market for lemongrass oil has seen significant growth, with projections estimating a market value of USD 231.4 million by 2025 (Sharma, 2019) [32].

Lemongrass grows in compact clumps, reaching up to 1.8 meters in height, and its leaves are rich in essential oils, with key constituents including citral, geraniol, and citronellol (Srivastava *et al.*, 2013) [34]. Due to its adaptability, fast growth, and ability to prevent soil erosion, lemongrass is an ideal species for agroforestry systems, particularly as an intercropping option (Caron *et al.*, 2019) [5]. Its essential oils are widely used in pharmaceuticals, cosmetics, and food industries, making lemongrass one of the top ten oil-bearing crops globally (Dutta *et al.*, 2014) [10]. Furthermore, lemongrass supports livelihoods by providing income through the growing market for medicinal and aromatic plants (Suresh *et al.*, 2012) [36].

Materials and Methods

Experimental Location

The present investigation was conducted at the Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, during the 2022-23 and 2023-24 growing seasons. Raipur is situated in the southeastern part of Chhattisgarh at 21°23'39.77"N latitude and 81°69'44.30"E longitude, with an elevation of 295 meters above mean sea level. The soil at the experimental site was clay to loam in texture, making it suitable for lemongrass cultivation. The experiment was conducted in a 24-year-old Mangium plantation, where lemongrass was grown as an intercrop between the Mangium rows. The trees were spaced 5 meters apart row-to-row and 3 meters apart tree-to-tree.

Field Preparation and Planting

Before planting, the field was thoroughly prepared by plowing with a tractor, followed by leveling using the planking method to create an even surface for transplantation. Lemongrass was planted in 2.5 m x 2 m plots with a plant spacing of 40 cm x 30 cm. A total of 24 plots were established within the agroforestry system. Rooted lemongrass slips, measuring 25 to 30 cm in length, were used for propagation. These slips were transplanted into the experimental field during June 2022 and June 2023.

Experimental Design

The experiment was arranged in a Randomized Block Design (RBD) with eight different lemongrass treatments (varieties) assigned to the plots. Each treatment was replicated three times for statistical accuracy. The eight treatments included: T1 - Krishna, T_2 - CG1, T_3 - Pragati, T_4 - Neema, T_5 - Kaveri, T_6 - CKP-25, T_7 - Praman, and T_8 - Kalam.

Growth and Yield Parameters

Growth parameters such as plant height, number of tillers per plant, leaf length, leaf width, plant spread in East-West (E-W) and North-South (N-S) directions, and Leaf Area Index (LAI) were recorded at each harvest. LAI was calculated by multiplying the leaf length and width by a conversion factor of 1.9 (Lazarov, 1965) [22], and dividing by plant spacing. Yield parameters, including fresh and dry herbage yield, were estimated by harvesting five randomly selected plants per plot, and recording their fresh and dried weights. Essential oil percentage was determined using hydro-distillation in a Clevenger-type apparatus following the method of Guenther (1950) and oil yield (l/ha) was calculated by multiplying the fresh leaf yield by the oil content. These parameters were recorded to evaluate the growth, yield, and oil extraction efficiency of different lemongrass varieties under a Mangium-based agroforestry system.

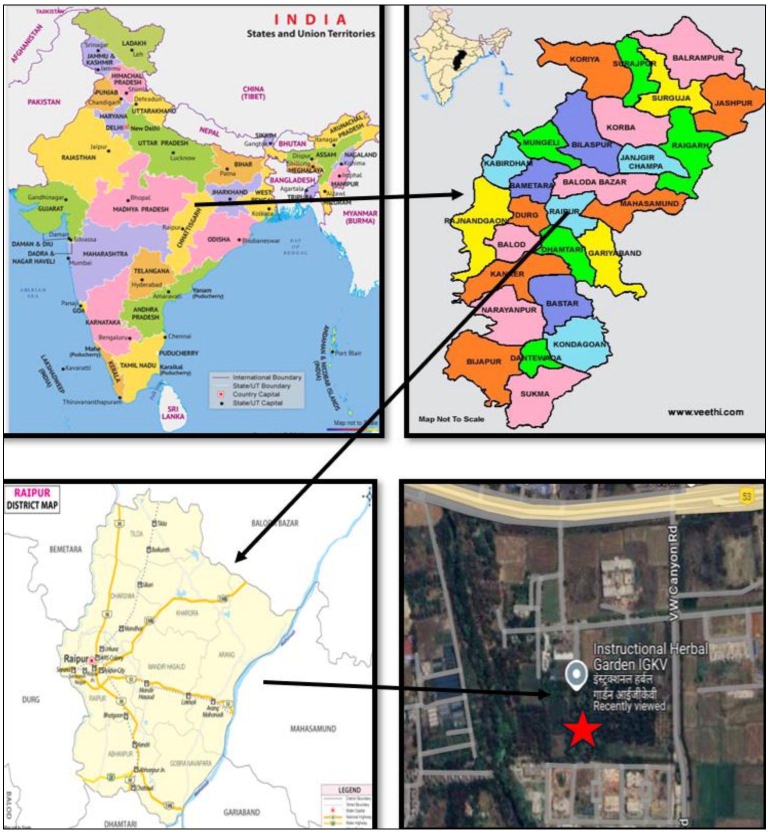

Fig 1: Location of experimental site

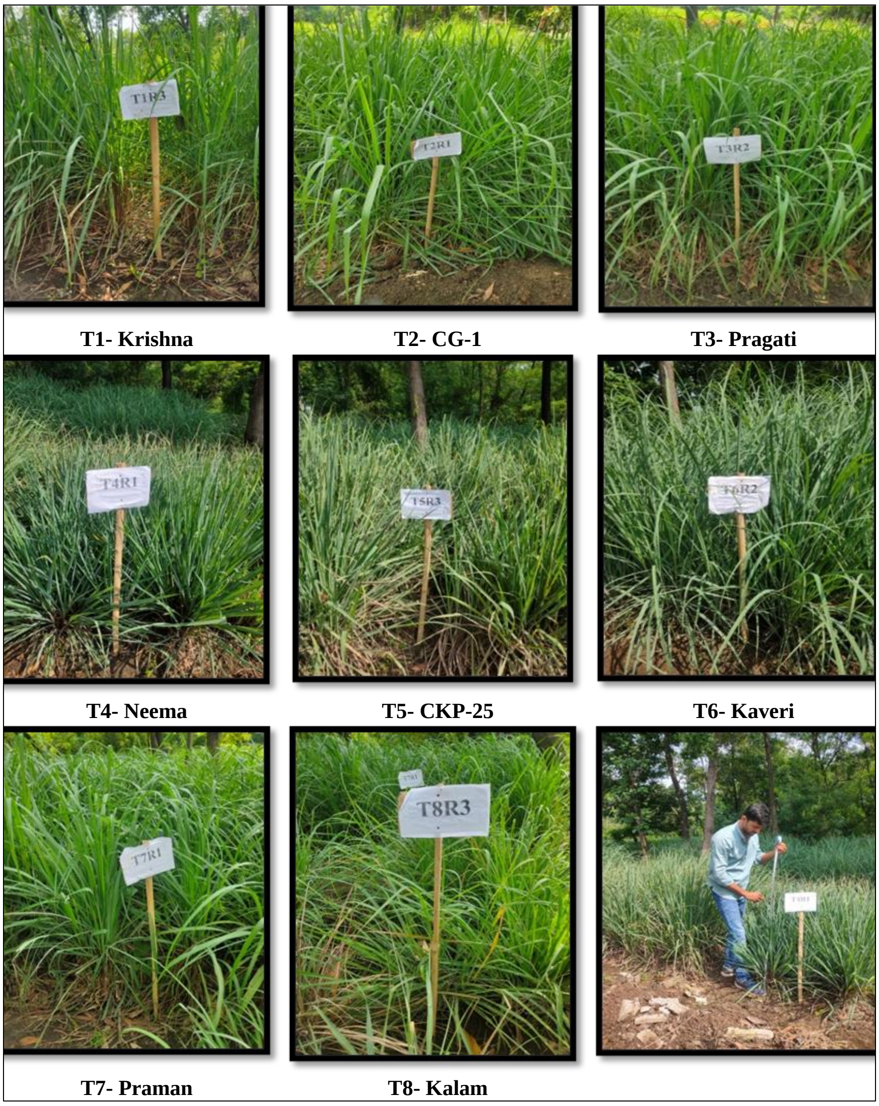

Plate 1: different treatments varieties of lemongrass

Plate 2: During the observation of growth parameters

Results and Discussion

The growth performance and yield attributes of different lemongrass varieties under the Mangium-based agroforestry system during the 2022-23 and 2023-24 seasons showed significant differences across plant height, number of tillers, plant spread, leaf area index (LAI), fresh yield, dry yield, oil percentage, and oil yield.

Growth Performance of Lemongrass

The growth performance of lemongrass varieties in a Mangium-based agroforestry system from 2022-23 to 2023-24 showed significant genotypic differences in plant height, tiller production, plant spread, and Leaf Area Index (LAI). T_1-Krishna had the highest plants (153.38 cm in 2022-23 and 157.20 cm in 2023-24), and T_8-Kalam had the lowest height (96.49 cm in 2022-23 and 99.77 cm in 2023-24). During both seasons, T_4-Neema had the maximum tiller production (64.16 and 65.53 cm) and plant spread (71.27 cm and 75.52 cm), whereas T_8-Kalam had the lowest tiller count (29.24 and 31.50 cm) and plant spread (43.96 cm and 47.05 cm). LAI was highest in T_2-CG-1 (38.77 and 40.10) and T_7-Praman (36.90 and 38.47), indicating increased light capture and photosynthetic efficiency. T_8-Kalam (16.19 and 17.02) and T_6-CKP-25 (18.87 and 20.06) showed the lowest LAI, indicating limited adaptability to shaded environments. These findings highlight the impact of genotypic diversity and the shading effects of *Acacia mangium* on lemongrass development, emphasizing the importance of variety-specific recommendations for optimal performance in agroforestry systems.

Ali *et al.* (2011) [3] and Nagarajaiah *et al.* (2012) [26] reported that agroforestry systems might reduce plant height in certain medicinal plants, highlighting the complexity of tree-crop interactions and the need for selecting varieties that can thrive under specific conditions. The varietal differences observed in this study align with findings from Gupta *et al.* (2013) [16] and Pandey *et al.* (2019) [28], who also reported significant differences in plant height across lemongrass varieties. These studies underscore the importance of genetic factors in determining growth potential under diverse agroforestry systems. Daswir *et al.* (2009) [8], Kebede & Chala (2016) [20], and Hamed *et al.* (2017) [18] noted that wider plant spacing tends to increase tiller numbers. The higher tiller numbers observed in this study, compared to findings by MoA (2016) [1] and Syukur & Trisilawati (2019) [38], may be due to the favorable conditions provided by the agroforestry system. Similar observations were made by Susanto *et al.* (2021) [37], who reported that agroforestry systems improve plant growth compared to monocultures. This variation emphasizes the impact of genetic traits on plant growth, particularly in agroforestry systems where light capture is crucial. Studies by Wang *et al.* (2015) [41] and Hafni *et al.* (2019) [17] support this, noting that shade-tolerant varieties, such as T_4-Neema, have an advantage in optimizing resource use and capturing sunlight more effectively. This ability to expand and utilize available light could contribute to the superior performance of T_4-Neema compared to T_8-Kalam, which exhibited the lowest plant spread.

Furthermore, observations by Suci and Heddy (2018) [35] suggest that lower light intensity can lead to wider canopy formation, implying that agroforestry conditions might enhance plant spread for certain varieties. The findings of Patil *et al.* (2001) [29] and Vidya *et al.* (2013) [40] provide further context by emphasizing the role of genetic diversity and ploidy levels in plant spread. Their studies on *Plectranthus forskohlii* and Ashwagandha showed that certain varieties and ploidy levels significantly enhance plant spread and growth. Chairudin *et al.*, (2015) [7] explained that tolerant genotypes adapt to low light conditions by increasing their leaf area and chlorophyll content, thereby maximizing light absorption and compensating for reduced light availability. Such adaptive traits are crucial for optimizing growth and productivity in diverse and shaded agroforestry settings. Additionally, Dendang and Sudomo (2020) [9] found that a moderate shade level of up to 30% in agroforestry systems can boost plant growth by providing a more favorable microclimate.

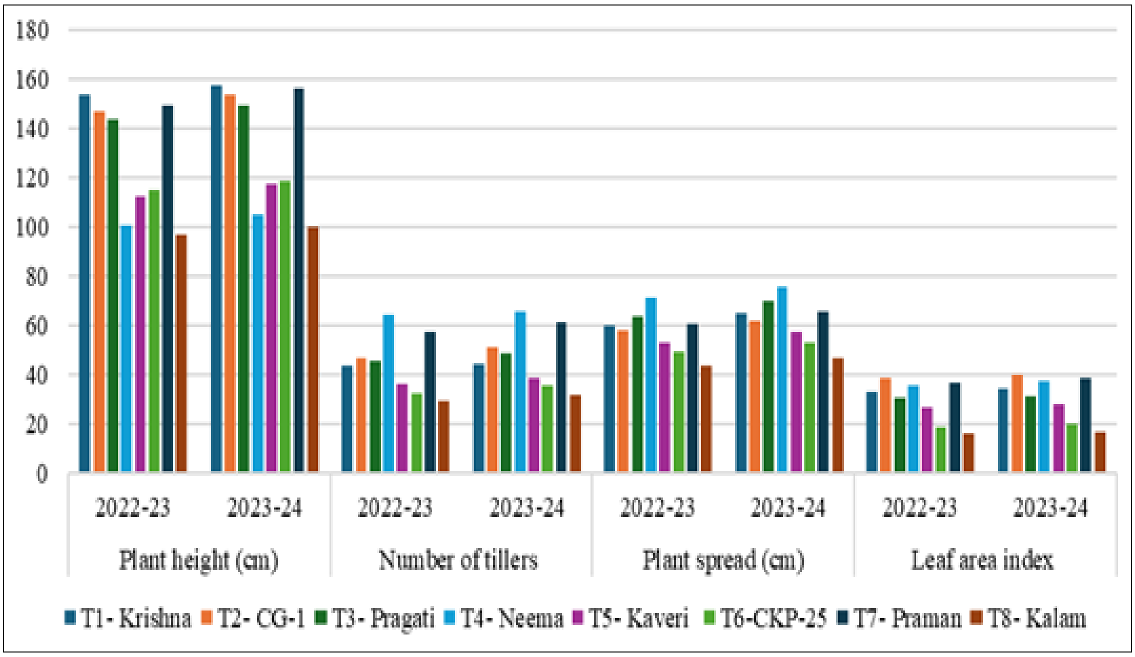

Fig 2: Average growth performance of different lemongrass varieties under mangium-based agroforestry system

Table 1: Average growth performance of different lemongrass varieties under mangium-based agroforestry system

Average Growth Performance of Different Lemongrass Varieties at Each Harvest Stage								
Treatments	Plant height (cm)		Number of tillers		Plant spread (cm)		Leaf area index	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1-Krishna	153.38	157.20	43.37	44.21	60.01	64.84	33.13	34.20
T_2-CG-1	146.60	153.88	46.91	50.92	57.96	61.51	38.77	40.10
T_3-Pragati	143.65	149.02	45.73	48.45	63.95	69.70	30.31	31.43
T_4-Neema	100.64	105.12	64.16	65.53	71.27	75.52	35.24	37.38
T_5-Kaveri	112.33	117.12	36.37	38.72	52.95	57.42	26.95	28.33
T_6-CKP-25	114.75	118.40	32.71	35.73	49.39	53.13	18.87	20.06
T_7-Praman	149.22	156.06	57.12	61.25	60.66	65.34	36.90	38.47
T_8-Kalam	96.49	99.77	29.24	31.50	43.96	47.05	16.19	17.02
CD @ 5%	4.10	4.73	5.12	5.98	3.39	3.374	1.756	1.598
SE(m)	1.35	1.56	1.69	1.97	1.12	1.11	0.58	0.53

Yield Attributes of Lemongrass

Lemongrass varieties differed significantly in terms of fresh yield, dry yield, oil percentage, and oil yield. T_4-Neema produced the highest fresh yields (128.16 q/ha in 2022-23 and 131.01 q/ha in 2023-24), followed by T_7-Praman and T_2-CG-1, while T_8-Kalam had the lowest fresh yields (87.34 q/ha and 100.56 q/ha). T_4-Neema continued to lead in dry yield, with 35.24 q/ha in 2022-23 and 36.03 q/ha in 2023-24, while T_6-CKP-25 had the lowest yields (25.15 q/ha and 29.09 q/ha). T_1-Krishna had the highest oil percentage (0.75% in both seasons), followed by T_8-Kalam (0.735-0.745%) and T_5-Kaveri (0.71-0.70%), while T_4-Neema had the lowest oil percentage (0.64% and 0.66%). T_1-Krishna also achieved the highest oil yield (87.94 l/ha and 91.97 l/ha), with T_7-Praman performing similarly well (84.15 l/ha and 91.25 l/ha). The lowest oil yield was recorded in T_6-CKP-25 (63.74 l/ha^{-1} and 74.64 l/ha^{-1}). These findings highlight the critical role of genotype selection in maximizing biomass, oil production, and economic returns in Mangium-based agroforestry systems.

Yield reduction in intercropping systems is a common observation, as noted by Xu *et al*. (2008) [42], primarily due to increased interspecific competition for space, air circulation, sunlight, and nutrients. Similar findings have been reported by Kar *et al*. (2019) [19], Keprate (2021) [21], and Gautam (2023) [15], emphasizing that resource limitations in intercropping systems often result in reduced yields. However, in systems with ample resources, plants tend to exhibit more vigorous growth. This steady availability of nutrients enables high-yielding varieties to accumulate more dry matter, ultimately increasing dry herb yield per plant and per hectare, as demonstrated by AL-Mansour *et al*. (2017) [4] and Ejigu *et al*. (2021) [13].

El-Sayed *et al*. (2018) [14], suggesting that genetic factors influence not only oil composition but also yield across different growth stages. Studies by Shahi *et al*. (2012) [31] and Abdou *et al*. (2014) [2] have further demonstrated that nutrient management enhances oil content, indicating the combined importance of genetic potential and nutrient availability. Verma *et al*. (2015) [39] evaluated eight lemongrass cultivars in the Himalayan region and found considerable variation in essential oil yield and composition, influenced by both cultivar differences and harvest seasons. Similarly, Dutta *et al*. (2017) [12] examined 120 lemongrass genotypes and observed significant genetic variability in traits such as plant height, tiller count, citral content, herbage yield, and oil yield, reinforcing the critical role of genetic diversity in optimizing lemongrass yield and quality. Overall, the interplay between genetic potential and environmental inputs, particularly nutrient management, plays a vital role in achieving optimal lemongrass oil yields. Proper genotype selection tailored to specific environmental conditions and nutrient regimes can maximize both biomass and oil production.

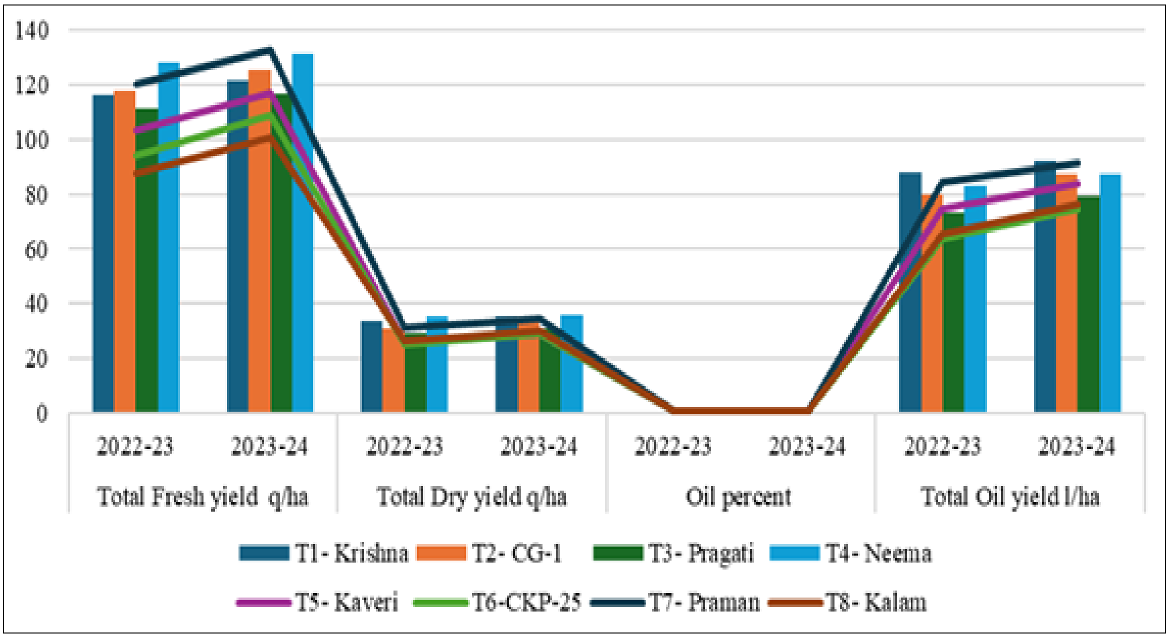

Fig 3: Yield attributes of different lemongrass varieties under mangium-based agroforestry system

Table 2: Yield attributes of different lemongrass varieties under mangium-based agroforestry system

Yield attributes of different lemongrass varieties under mangium-based agroforestry system								
Treatments	**Total Fresh yield q/ha**		**Total Dry yield q/ha**		**Oil percent**		**Total Oil yield l/ha**	
	2022-23	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**	**2022-23**	**2023-24**
T_1-Krishna	115.96	121.28	33.63	35.17	0.75	0.75	87.94	91.97
T_2-CG-1	117.66	125.36	30.94	32.97	0.67	0.685	79.81	87.23
T_3-Pragati	111.26	116.43	29.60	30.97	0.65	0.67	73.25	78.98
T_4-Neema	128.16	131.01	35.24	36.03	0.64	0.66	82.88	87.34
T_5-Kaveri	103.22	116.64	25.91	29.28	0.71	0.7	74.83	83.59
T_6-CKP-25	93.86	108.56	25.15	29.09	0.665	0.675	63.74	74.64
T_7-Praman	120.35	132.72	31.41	34.64	0.685	0.675	84.15	91.25
T_8-Kalam	87.34	100.56	26.20	30.17	0.735	0.745	65.44	76.17
CD@ 5%	8.125	8.507	2.182	2.318	0.013	0.014	5.743	5.962
SE(m)	2.68	2.80	0.72	0.76	0.004	0.005	1.89	1.97

Conclusion
The study demonstrated the potential of lemongrass varieties T_4-Neema and T_1-Krishna for biomass and oil production under a Mangium-based agroforestry system. T_4-Neema's high fresh and dry yield, coupled with its extensive plant spread and tiller production, make it ideal for biomass production. In contrast, T_1-Krishna's high oil percentage and yield make it suitable for oil production. These findings have implications for sustainable agroforestry practices, suggesting that carefully selected lemongrass varieties can optimize resource use and promote efficient production under partial shading. Further research should focus on exploring the economic viability and environmental benefits of integrating lemongrass into agroforestry systems.

Acknowledgement
The authors are grateful to the Department of Forestry, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, for providing the resources and support required to undertake this study. Special thanks to Dr. Pratap Toppo, the main advisor and in-charge of the Herbal Garden where the experiment was conducted, for his help and contributions during the research time. Finally, we would like to express our deepest thanks to our family, friends, and coworkers for their constant support, whether directly or indirectly, throughout the research period.

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