Journal of Advances in Biology & Biotechnology

Volume 27, Issue 12, Page 476-484, 2024; Article no.JABB.128390
ISSN: 2394-1081

Enhancing Oil Yield and Quality of *Cymbopogon winterianus* through Organic Manures in *Moringa oleifera*-Based Agroforestry Systems

KND Prasanna Kumar Dora [a*] and Sameer Dainel [a]

[a] Department of Agro-forestry and Silviculture, College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jabb/2024/v27i121795

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/128390

Original Research Article

Received: 14/10/2024
Accepted: 17/12/2024
Published: 20/12/2024

ABSTRACT

This study evaluated the impact of organic manures on the oil attributes and quality parameters of *Cymbopogon winterianus* (citronella java) under *Moringa oleifera*-based agroforestry and open-field systems during 2022–2023. A randomized block design with 14 nutrient management treatments, including combinations of farmyard manure (FYM), vermicompost, and neem cake, was employed. Results indicated that the combined application of FYM, vermicompost, and neem cake (33.3% each) significantly enhanced oil content, oil recovery, and total oil yield compared to the control. Specifically, this combination yielded the highest oil content (1.14%), average oil recovery (0.66%), and total oil yield (81.52 L ha^{-1}) under shade conditions. Physical parameters such as specific gravity (0.87–0.88), refractive index (1.47), and optical rotation (-2.87 to -2.91°) were consistent with

**Corresponding author: E-mail: pk768793@gmail.com;*

Cite as: *Dora, KND Prasanna Kumar, and Sameer Dainel. 2024. "Enhancing Oil Yield and Quality of Cymbopogon Winterianus through Organic Manures in Moringa Oleifera-Based Agroforestry Systems". Journal of Advances in Biology & Biotechnology 27 (12):476-84. https://doi.org/10.9734/jabb/2024/v27i121795.*

BIS standards and unaffected by nutrient treatments. Similarly, chemical properties like acid value (1.21–1.24) and ester value (22.12–24.12) remained within standard specifications. Notably, the agroforestry system improved oil yield and quality parameters compared to open-field conditions, attributed to the favourable microclimatic conditions and nutrient cycling provided by *Moringa oleifera*.

Keywords: Citronella java oil; oil attributes; organic nutrient management; quality parameters of oil.

1. INTRODUCTION

Agroforestry, an ecologically sustainable land-use system, integrates trees and agricultural crops, offering environmental, economic, and social benefits. Among its numerous applications, intercropping aromatic plants such as *Cymbopogon winterianus* (citronella java) under tree canopies like *Moringa oleifera* has gained significant interest. This practice optimizes land use while enhancing crop productivity and ecosystem resilience. Among agroforestry models, systems incorporating medicinal and aromatic plants have shown promise in enhancing income for farmers while providing environmental benefits such as improved soil fertility, erosion control, and carbon sequestration (Jose, 2009). When grown alongside *Moringa oleifera*, commonly known as moringa, it benefits from the partial shade and improved soil conditions provided by the moringa canopy, which can lead to enhanced growth and yield attributes (Kaushal et al*.,* 2014).

Citronella java (*Cymbopogon winterianus*), a key aromatic grass, is widely cultivated for its essential oil, which holds immense industrial value due to its applications in perfumes, cosmetics, and medicinal products. The oil's quality and yield are influenced by agronomic practices, particularly soil fertility management (El-Sayed et al., 2018; Nandapure et al., 2015; Da Costa et al., 2020; Singh and Singh, 1992; Prakasa et al., 1991). Organic manures, a sustainable alternative to chemical fertilizers, play a crucial role in improving soil health and plant growth. They not only enhance nutrient availability but also improve the quality and quantity of citronella oil, which is influenced by factors such as its chemical composition and yield (Sharma & Singh, 2019).

Organic manures, such as farmyard manure, vermicompost, and green manure, play a pivotal role in sustainable agriculture by enriching soil nutrient content and promoting microbial activity (Manna et al., 2005). These amendments provide essential nutrients to plants and improve soil structure, which in turn enhances water retention and root development. Their impact on aromatic plants, particularly in agroforestry setups, remains an area of interest due to the dual benefit of increased crop productivity and reduced dependency on chemical fertilizers. Research suggests that organic amendments can positively influence the growth and essential oil yield in aromatic crops like citronella, though results may vary based on application rates, soil type, and environmental conditions (Singh & Prasad, 2016).

The inclusion of *Moringa oleifera* in agroforestry systems provides additional advantages, such as improved microclimatic conditions and nutrient cycling, owing to its deep rooting system and nutrient-rich litter (Patel, 2021). However, the interaction of organic manures with citronella oil attributes in both shaded (*Moringa* canopy) and open-field conditions remains underexplored.

This study aims to evaluate the effect of organic manures on the oil yield and quality of citronella java under *Moringa*-based agroforestry and open-field systems. The findings are expected to provide insights into sustainable agronomic practices, contributing to the optimization of citronella cultivation while promoting environmentally friendly farming systems.

2. MATERIALS AND METHODS

This study investigates the effects of different organic manures on the oil parameters of citronella when cultivated under a moringa-based agroforestry system compared to an open-field system. By examining these effects, the research aims to identify optimal organic amendments for improving the productivity of citronella in agroforestry setups, thereby contributing to sustainable agricultural practices and enhancing the economic viability of aromatic crops in diversified farming systems.

2.1 Study Area

The study was conducted in the kharif season of 2022-2023. The research occurred at the central research farm of the Department of Agro-forestry and Silviculture at the College of Forestry, Sam

Higginbottom University of Agriculture, Technology, and Science. The experimental site in Prayagraj district was located at a latitude of 25° 40' N and longitude of 81° 85' E, at an altitude of 92 meters above sea level. This site is adjacent to the Yamuna Riverbank to the east and Indalpur village to the north. Citronella flourishes in tropical and subtropical climates. It requires abundant moisture and sunlight for optimal growth and development. High atmospheric humidity, along with 200–250 cm of annual rainfall, positively influences plant growth. In areas with insufficient rainfall, supplemental irrigation can support growth; however, in Uttar Pradesh, annual rainfall ranges significantly from west to east, from 600 to 1000 mm (24 to 40 inches) to 1000 to 2000 mm (40 to 80 inches).

2.2 Experimental Details

The present study investigated the impact of organic manures on oil attributes of citronella crop. A Randomized Block Design (RBD) was utilized to address potential spatial variations within the research site. This experimental setup aims to furnish a comprehensive insight into the impact of each treatment on the dependent variable and to identify potential interactions among the treatment combination. The experiment will be replicated thrice to ensure robust statistical analysis and to address block-level variability. The gathering of data will encompass a thorough evaluation of oil attributes, such as oil content, average oil recovery, total oil yield, Specific gravity at 27^0C, Optical rotation at (^{0}), Acid value, Ester value. The details of treatment combinations are T_0 - Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake.

2.3 Statistical Analysis

The data was recorded and transformed using the Analysis of Variance technique. The analysed data was organized into a table for result interpretation. The ANOVA table was utilized for hypothesis testing. Treatment effects were assessed using the "F" (variance ratio) table. A significant effect was determined if the calculated value surpassed the table value. Standard agricultural statistical procedures from Gomez (1984) were adhered to. Data interpretation will rely on the critical difference value at a 0.05 probability level. The significance level will be indicated at 0.05 probabilities.

3. RESULTS AND DISCUSSION

3.1 Oil content (%) of Citronella Java

The average oil content was estimated by Clevenger apparatus and the data obtained is presented in Table. 1. The oil content in Java citronella was significantly influenced by the nutrient management treatments comprised of combined application of FYM, vermicompost and Neem-cake in both the years ranges from the 0.86 to 1.15. The application of 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake significantly increased the content as compared to control. Similar result was reported by Pareek et al*.,* (1983). Further, it is noticed that the oil content was found to increase with every higher dose of FYM and significantly highest oil content was observed with higher dose of FYM. The results agree with the findings of Maheshwari et al*.,* (1991).

3.2 Average Oil Recovery (%) of Citronella Java

The detailed of the results was represented in Table 2 oil recovery was significantly influenced with the application of 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake doses as compared to control (T_0). Significantly higher recovery was obtained from the herbage supplied with higher FYM Range from 0.52 to 0.66. However, the recovery per cent differences among the doses were statistically non-significant. Increased in oil recovery was reported with the application of FYM @ 10 t ha^{-1} (Pareek et al*.* 1983) and FYM@ 15 t ha^{-1} (Maheshwari et al.1991) as compared to control.

3.3 Total Oil Yield (lit ha^{-1}) of Citronella Java

The data regarding the total oil yield of citronella java as influenced by the nutrient management is presented in Table 3. Application of different dose of 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake indicated that significantly highest oil yield than all other treatments and T, (control) during both the years. The value ranges from the 66.64 to 82.02. Similar results were reported by Pareek et al. (1983) and Maheshwari et al. (1991).

Quality parameters of citronella java oil:

Physical parameters: As per the BIS standards for Java citronella oil (IS: 512-1988), the specific gravity of Java citronella oil at 27°C was in the range of 0.8743 to 0.8893. Refractive index was in the range of 1.4624 to 1.4714 at 27°C, optical rotation was in the range of (-) 0.5° to (-) 5.0° and solubility was 80% in 1 to 2 volumes (Akbar and Saxena, 2009). The physical properties of oil observed in the present investigation are as per the BIS standard, and in general, being tested for any adulteration in the oil.

3.4 Specific Gravity 27^{0}C of Citronella Java

On the perusal of the data Table 4 it is revealed that the specific gravity at 27^{0}C were not influenced by the application various treatments of nutrient management under study. The specific gravity of the oil was in the range of 0.87 to 0 88 on both open and shade conditions in consecutive years.

3.5 Refractive Index of Citronella Java Oil

The represented in the Table 5 it is revealed that the refractive index of citronella java oil were not influenced by the application various treatments of nutrient management under study. The refractive index of the oil was in the range of 1.4690 to 1.694 on both open and shade conditions in consecutive years.

3.6 Optical Rotation (^{0}) of Citronella Java Oil

The represented in the Table 6 it is revealed that the optical rotation of citronella java oil were not influenced by the application various treatments of nutrient management under study. The optical rotation of the oil was in the range of -2.87 to -2.91 on both open and shade conditions in consecutive years.

Chemical parameters:

3.7 Acid Value of Citronella Java Oil

The data shown Table 7 revealed that the acid value of Java citronella oil was not influenced with the application of various treatments of nutrient management. The results are in accordance with the findings of Chinnamma and Aiyer (1989) and Rao (2001). The acid value was in the range of 1.21 to 1.24 however, no trend of acid value was noticed as influenced by different treatments. These values were also found as per the standard specified to Java citronella oil.

Table 1. Effect of different organic manures on oil content (%) of Citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during consecutive years, from 2022 to 2023

Oil Content (%)	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	0.88	0.86	0.87	0.88	0.90	0.89
T_1	0.97	0.99	0.98	0.99	1.01	1.00
T_2	0.98	1.01	1.00	1.01	1.03	1.02
T_3	0.98	0.98	0.98	1.01	1.03	1.02
T_4	0.99	1.02	1.01	1.02	1.06	1.04
T_5	0.98	0.99	0.99	1.02	1.05	1.04
T_6	0.97	1.01	0.99	1.02	1.04	1.03
T_7	1.01	1.01	1.01	1.02	1.05	1.04
T_8	0.99	0.99	0.99	1.01	1.06	1.04
T_9	0.99	1.10	1.05	1.02	1.06	1.04
T_{10}	0.98	1.10	1.04	1.02	1.05	1.04
T_{11}	0.98	1.02	1.00	1.01	1.06	1.04
T_{12}	0.97	0.99	0.98	1.01	1.02	1.02
T_{13}	1.01	1.10	1.06	1.12	1.15	1.14
SE(d)	0.0182	0.02381	0.01749	0.02539	0.02216	0.01235
C.D. @5%	0.04663	0.05016	0.03717	0.0495	0.04517	0.03453

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake.*

Table 2. Effect of different organic manures on Average oil recovery (%) of Citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during consecutive years, from 2022 to 2023

Avg. Oil recovery (%)	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	0.52	0.51	0.51	0.59	0.58	0.58
T_1	0.62	0.62	0.62	0.64	0.65	0.65
T_2	0.63	0.62	0.63	0.64	0.65	0.65
T_3	0.62	0.62	0.62	0.63	0.65	0.64
T_4	0.62	0.64	0.63	0.65	0.66	0.66
T_5	0.63	0.63	0.63	0.64	0.65	0.65
T_6	0.62	0.63	0.63	0.63	0.65	0.64
T_7	0.63	0.62	0.63	0.64	0.66	0.65
T_8	0.62	0.63	0.63	0.63	0.65	0.64
T_9	0.64	0.63	0.64	0.65	0.66	0.66
T_{10}	0.64	0.64	0.64	0.64	0.66	0.65
T_{11}	0.63	0.63	0.63	0.64	0.65	0.65
T_{12}	0.63	0.63	0.63	0.64	0.65	0.65
T_{13}	0.64	0.65	0.65	0.65	0.66	0.66
SE(d)	0.01516	0.01351	0.01183	0.01239	0.01367	0.01017
C.D. @5%	0.03228	0.02877	0.02518	0.02638	0.02911	0.02165

***Note:** T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake*

Table 3. Effect of different organic manures on total oil yield (lit ha^{-1}) of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during consecutive years, from 2022 to 2023

Avg. Oil recovery (%)	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	66.65	66.64	66.65	67.50	68.50	68.00
T_1	67.25	67.61	67.43	72.15	69.25	70.70
T_2	79.25	67.85	73.55	73.54	70.12	71.83
T_3	79.46	68.25	73.86	74.46	72.25	73.36
T_4	79.46	78.35	78.91	75.45	72.35	73.90
T_5	78.35	68.34	73.35	79.45	73.25	76.35
T_6	80.02	68.35	74.19	78.45	73.26	75.86
T_7	80.01	68.36	74.19	78.25	75.45	76.85
T_8	69.35	68.32	68.84	79.32	75.46	77.39
T_9	75.24	78.25	76.75	81.02	76.25	78.64
T_{10}	70.65	80.12	75.39	80.02	79.25	79.64
T_{11}	79.26	79.45	79.36	79.85	80.25	80.05
T_{12}	79.25	79.12	79.19	79.81	80.25	80.03
T_{13}	80.01	81.21	80.61	81.02	82.02	81.52
SE(d)	1.60859	1.68642	1.17087	1.35593	1.75897	1.11771
C.D. @5%	3.42405	3.5897	2.49232	2.88624	3.74414	2.37915

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake.*

Table 4. Effect of different organic manures on Specific gravity 27^{0}C of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during 2022 to 2023

Specific gravity 27^{0}C	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	0.88	0.88	0.88	0.88	0.88	0.88
T_1	0.88	0.88	0.88	0.88	0.88	0.88
T_2	0.88	0.88	0.88	0.88	0.88	0.88
T_3	0.88	0.88	0.88	0.88	0.88	0.88
T_4	0.88	0.88	0.88	0.88	0.88	0.88
T_5	0.88	0.88	0.88	0.88	0.88	0.88
T_6	0.88	0.88	0.88	0.88	0.88	0.88
T_7	0.88	0.88	0.88	0.88	0.88	0.88
T_8	0.88	0.88	0.88	0.88	0.88	0.88
T_9	0.88	0.88	0.88	0.88	0.88	0.88
T_{10}	0.88	0.88	0.88	0.88	0.88	0.88
T_{11}	0.88	0.88	0.88	0.88	0.88	0.88
T_{12}	0.88	0.87	0.87	0.88	0.88	0.88
T_{13}	0.88	0.88	0.88	0.88	0.88	0.88

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake*

Table 5. Effect of different organic manures on Refractive Index of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during 2022 to 2023

Refractive Index	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	1.47	1.47	1.47	1.47	1.47	1.47
T_1	1.47	1.47	1.47	1.47	1.47	1.47
T_2	1.47	1.47	1.47	1.47	1.47	1.47
T_3	1.47	1.47	1.47	1.47	1.47	1.47
T_4	1.47	1.47	1.47	1.47	1.47	1.47
T_5	1.47	1.47	1.47	1.47	1.47	1.47
T_6	1.47	1.47	1.47	1.47	1.47	1.47
T_7	1.47	1.47	1.47	1.47	1.47	1.47
T_8	1.47	1.47	1.47	1.47	1.47	1.47
T_9	1.47	1.47	1.47	1.47	1.47	1.47
T_{10}	1.47	1.47	1.47	1.47	1.47	1.47
T_{11}	1.47	1.47	1.47	1.47	1.47	1.47
T_{12}	1.47	1.47	1.47	1.47	1.47	1.47
T_{13}	1.47	1.47	1.47	1.47	1.47	1.47
SE(d)	0.03265	0.03104	0.02145	0.0325	0.03617	0.01926
C.D. @5%	0.0695	0.06606	0.04566	0.06918	0.07699	0.041

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake*

3.8 Ester value of Citronella Java Oil

The data shown Table 8 revealed that the ester value of Java citronella oil was not influenced with the application of various treatments of nutrient management. The results are in accordance with the findings of Chinnamma and Aiyer (1989) and Rao (2001). The ester value was in the range of 22.12 to 24.12. These values were also found as per the standard specified to Java citronella oil (Yadav et al. 2020).

Table 6. Effect of different organic manures on Optical rotation (^{0}) of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during 2022 to 2023.

Optical rotation	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	-2.87	-2.80	-2.84	-2.88	-2.89	-2.89
T_1	-2.88	-2.89	-2.89	-2.89	-2.90	-2.90
T_2	-2.87	-2.90	-2.89	-2.89	-2.90	-2.90
T_3	-2.88	-2.89	-2.89	-2.89	-2.89	-2.89
T_4	-2.89	-2.90	-2.90	-2.90	-2.90	-2.90
T_5	-2.88	-2.89	-2.89	-2.89	-2.89	-2.89
T_6	-2.87	-2.89	-2.88	-2.90	-2.89	-2.90
T_7	-2.87	-2.89	-2.88	-2.90	-2.90	-2.90
T_8	-2.88	-2.89	-2.89	-2.89	-2.89	-2.89
T_9	-2.89	-2.90	-2.90	-2.89	-2.89	-2.89
T_{10}	-2.88	-2.89	-2.89	-2.90	-2.90	-2.90
T_{11}	-2.87	-2.87	-2.87	-2.89	-2.89	-2.89
T_{12}	-2.87	-2.89	-2.88	-2.89	-2.90	-2.90
T_{13}	-2.89	-2.90	-2.90	-2.90	-2.91	-2.91
SE(d)	0.05382	0.05799	0.04391	0.06814	0.05604	0.04681
C.D. @5%	0.11456	0.12343	0.09348	0.14504	0.11929	0.09963

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake*

Table 7. Effect of different organic manures on acid value of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during consecutive years, from 2022 to 2023

Acid Value	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	1.21	1.22	1.22	1.22	1.23	1.23
T_1	1.21	1.22	1.22	1.22	1.24	1.23
T_2	1.22	1.23	1.23	1.22	1.23	1.23
T_3	1.22	1.22	1.22	1.23	1.23	1.23
T_4	1.21	1.23	1.22	1.22	1.24	1.23
T_5	1.21	1.22	1.22	1.23	1.23	1.23
T_6	1.21	1.22	1.22	1.23	1.23	1.23
T_7	1.22	1.23	1.23	1.23	1.24	1.24
T_8	1.21	1.22	1.22	1.23	1.23	1.23
T_9	1.22	1.23	1.23	1.23	1.24	1.24
T_{10}	1.22	1.23	1.23	1.23	1.24	1.24
T_{11}	1.21	1.22	1.22	1.22	1.23	1.23
T_{12}	1.21	1.22	1.22	1.22	1.23	1.23
T_{13}	1.22	1.23	1.23	1.23	1.24	1.24
SE(d)	0.05039	0.05271	0.0325	0.06212	0.04948	0.04000
C.D. @5%	0.02367	0.02476	0.01527	0.02918	0.02324	0.01879

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake.*

Table 8. Effect of different organic manures on Ester value of citronella java under *Moringa oleifera* based agro-forestry system open and shade condition during consecutive years, from 2022 to 2023.

Acid Value	Open Conditions			Shade (Moringa Based)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	22.25	23.25	22.75	22.26	22.27	22.27
T_1	22.26	23.28	22.77	23.30	22.30	22.80
T_2	22.14	23.27	22.71	23.30	23.31	23.31
T_3	22.16	23.29	22.73	22.32	23.30	22.81
T_4	23.12	24.10	23.61	22.34	23.33	22.84
T_5	22.15	23.32	22.74	22.34	23.21	22.78
T_6	22.12	23.30	22.71	22.35	23.22	22.79
T_7	23.02	23.31	23.17	22.35	23.25	22.80
T_8	22.21	24.11	23.16	22.34	23.32	22.83
T_9	23.11	24.11	23.61	23.30	23.34	23.32
T_{10}	23.01	24.10	23.56	23.30	23.26	23.28
T_{11}	23.10	24.10	23.60	22.30	23.36	22.83
T_{12}	22.21	23.26	22.74	22.36	23.35	22.86
T_{13}	23.12	24.12	23.62	23.31	23.37	23.34
SE(d)	0.477	0.42174	0.25465	0.456	0.51388	0.30863
C.D. @5%	1.01534	0.89772	0.54205	0.97063	1.09385	0.65695

**Note: T_0 -Control, T_1- 50% FYM+50% Neem cake, T_2- 50% FYM+50% Vermicompost, T_3- 50% Neem-cake +50% Vermicompost, T_4- 75% FYM+25% Vermicompost, T_5- 75% FYM+25% Neem-cake, T_6- 75% Neem-cake +25% Vermicompost, T_7- 75% Neem-cake +25% FYM, T_8- 75% Vermicompost +25% Neem-cake, T_9- 75% Vermicompost +25% FYM, T_{10}- 100% FYM, T_{11}- 100% Vermicompost, T_{12}- 100% Neem-cake, T_{13}- 33.3% FYM+33.3% Vermicompost +33.3% Neem-cake*

4. CONCLUSION

In conclusion, the study demonstrates the efficacy of organic manures in enhancing the oil yield and quality of *Cymbopogon winterianus* under agroforestry systems. The combination of 33.3% FYM, vermicompost, and neem cake was most effective, achieving the highest oil content (1.14%), recovery (0.66%), and yield (81.52 L ha^{-1}). Shade from *Moringa oleifera* improved microclimatic conditions, promoting better crop performance compared to open fields. Physical and chemical oil properties met BIS standards, ensuring market-ready quality. The findings advocate agroforestry's ecological and economic benefits, reducing reliance on chemical fertilizers. This sustainable practice supports soil health and farmer livelihoods. Future studies could assess its long-term viability and broader applicability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/128390