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Nutrient management influence on growth and yield of lemongrass (*Cymbopogon flexuosus cv.* Krishna) under new alluvial zone of West Bengal

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Abstract

A field experiment was conducted during 2023 from March to October as two harvests at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, to evaluate the effect of different doses of nutrient management practices on growth, yield, essential oil content and economics of lemongrass (*Cymbopogon flexuosus* cv. Krishna). Eleven treatments comprising graded levels of nitrogen, phosphorus and potassium fertilizers, farmyard manure (FYM) and an unfertilized control were laid out in a randomized block design with three replications. Observations were recorded for two successive harvests (July and October). The results revealed significant variation among treatments for all growth, yield and quality parameters. Application of NPK @ 120:60:60 kg ha^{-1} (treatment- 3) significantly improved the growth attributes such as plant height (ranging from 12.47 % & 12.60 %), number of tillers (64.31 % & 50.75 %) and leaves per clump (64.79 % & 50.46 %), fresh herbage yield (149.92 % and 165.33 %), dry herbage yield (198.73 % and 197.59 %), essential oil yield (189.23 % and 198.16 %) and oil content (15.79 % and 12.50 %) in the first and second harvest, respectively. These values were statistically at par with treatment-2 (NPK @ 100:60:60 kg ha^{-1}) and treatment -1 (NPK @ 80:60:60 kg ha^{-1}) for most traits. In contrast, the control treatment recorded the lowest yields and oil content. Principal component and correlation analysis confirmed a strong positive association between growth traits, herbage yield and essential oil yield. Economic analysis further indicated the highest net return and cost–benefit ratio under treatment-1 (NPK @ 80:60:60 kg ha^{-1}) in both the harvests. The study clearly demonstrated that an optimum dose of NPK fertilization plays a critical role in maximizing both biomass production and essential oil yield in lemongrass

Keywords: Nutrient management, lemongrass, growth, yield, essential oil, economics.

Introduction

The genus *Cymbopogon* is recognized as one of the leading oil-bearing aromatic crop groups worldwide, comprising nearly 140 species distributed across tropical and subtropical regions of Asia, Africa and America. India harbours 27 identified species of *Cymbopogon*, although only a few are cultivated commercially for essential oil production (Soenarko, 1997; Rao, 1997; Khanuja *et al*., 2005; Padalia *et al*., 2011; Shah *et al*., 2012). The principal cultivated species in India include *C. flexuosus* (East Indian lemongrass), *C. citratus* (West Indian lemongrass) and *C. pendulus* (North Indian lemongrass). Among them, *C. flexuosus*, commonly referred to as Malabar or Cochin grass, is native to India, Sri Lanka, Myanmar and Thailand and is commercially traded as East Indian lemongrass.

Lemongrass thrives best in tropical semi-arid climates with ample rainfall and abundant sunshine, with optimal growth occurring between 20°C and 30°C. In India, its cultivation is confined to Maharashtra, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, Chhattisgarh, Haryana, Madhya Pradesh, Bihar, Arunachal Pradesh, and Sikkim (Hansda and Meshram, 2001). India is the largest producer of lemongrass oil, contributing approximately 80% of the global output and exporting to more than 80 countries. Major importing nations include the United States, Belgium, Japan, Brazil, Germany and United Kingdom. In 2024, India's essential oil exports were valued at over USD 323 million (Statista, 2025). Despite its economic prominence, global lemongrass production remains relatively limited, with an estimated 1,000 tonnes produced from about 16,000 hectares worldwide (Gawali and Meshram, 2019). The global lemongrass oil market was valued at USD 38.02 million in 2020 and is projected to reach USD 81.43 million by 2028, according to CSIR-CIMAP, Lucknow.

In West Bengal, lemongrass cultivation is largely concentrated in the Darjeeling hills, where favourable climatic conditions and varied physiography support its growth. The crop occupies nearly 4,000 hectares in the state, producing approximately 250 tonnes annually. Notably, lemongrass accounts for nearly 61% of the total area under aromatic crops in India, underscoring its dominance in the sector (Samanta *et al*., 2025).

Lemongrass essential oil is highly valued for its strong citrus fragrance, primarily due to its high citral content (75–80%). Citral serves as a key raw material in the synthesis of aroma compounds such as α-ionone and β-ionone, which are extensively used in cosmetics, fragrances, pharmaceuticals and vitamin - A production (Paviani *et al*., 2006; Singh and Singh, 2014; Khan *et al*., 2014). Beyond its industrial applications, lemongrass oil possesses several medicinal properties, including analgesic, anti-inflammatory, antipyretic, diuretic, antimicrobial, antioxidant, and sedative effects (Onawunmi *et al*., 1984; Dorman *et al*., 2000; Chao and Young, 2000; Horne *et al*., 2001; Negrelle and Gomes, 2007). Additionally, the crop contributes to soil conservation due to its strong soil-binding capacity, making it effective for erosion control.

Given its commercial and therapeutic importance, improving agronomic practices for lemongrass cultivation has been a focus of research over the years. Early studies by Singh and Singh (1998) demonstrated that under semi-arid tropical conditions, nitrogen application up to 100 kg ha^{-1} significantly enhanced tiller number, plant height and leaf area index. Subsequently, Singh (1999) reported that maintaining a 0.75 IW:CPE moisture regime improved plant growth parameters, while nitrogen at 100 kg ha^{-1} optimized yield without significantly affecting oil content or quality.

Further research by Takankhar (2008) on palmarosa indicated that 100 kg nitrogen ha^{-1} $year^{-1}$ significantly improved tiller number and plant height. Zheljazkov *et al*., (2011) observed that nitrogen levels between 80–160 kg ha^{-1} increased lemongrass biomass yield, confirming the crop's strong responsiveness to nitrogen fertilization. Rajender *et al*., (2016) found that nitrogen at 100 kg ha^{-1} maximized yield without affecting oil content. Later, Saini *et al*., (2018) reported that early planting (20 March) resulted in the highest herbage yield, with nitrogen at 150 kg ha^{-1} performing best, though statistically similar to 100 kg ha^{-1}. Behura *et al*., (2020) further recommended the application of NPK at 100:50:50 kg ha^{-1} as the optimal nutrient dose for lemongrass cultivation. The objective of the present experiment was to evaluate the effect of different doses of nutrients on growth, yield, essential oil content and economics of lemongrass (*Cymbopogon flexuosus* cv. Krishna).

Materials and methods

Study site

The experiment was laid out at the Horticultural Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal during 2023 from March to October (*i.e.*, 1st cut at July and 2nd cut at October). The research station is located 9.75m above mean sea level with 23^0 North latitude and 890 East longitudes. The soil of the study site was of Gangetic alluvial sandy clay-loam in texture, with pH of 4.82 following pH meter method (Jackson, 1996), EC (dS m^{-1}) of 0.39, organic carbon of 1.15% (Walkey and Black method, 1967), available nitrogen of 282.81 kg ha^{-1} (Modified Kjeldhal's method by Jackson, 1973), available phosphorus of 62.81kg ha^{-1} (Modified Olsen method by Jackson, 1973) and available potassium of 340.8 kg ha^{-1} (Flame photometer method by Jackson, 1973) well drained with good water-holding capacity.

The treatment details are given Table 1. The 33 experimental plots (11 treatments with 3 replications each) were established in 2.4 m ×2.4 m dimension leaving 90 cm channels around the plots. During the end of February well rooted slips were separated from mother clumps and two slips were planted in the main field with spacing 60 cm × 60 cm. The planted slips were immediately irrigated after planting. The planting was done in the last day on the month of February 2023. The chemical fertilizers as such nitrogen, phosphorus and potassium were applied through Urea (46%), Single Super Phosphate (16%) and Muriate of Potash (60%) respectively. Primarily, one fourth spilt dose of nitrogen with half dose of phosphorus and potassium were applied. The remaining nitrogen was applied after 35 days. For phosphorus and potassium, the remaining half dose were applied after first harvest. Frequent irrigation was given at an interval of 10-15 days as and when required depending upon the soil moisture and climatic conditions. Oil percentage was thoroughly checked by distillation process followed by harvesting done twice as first harvest at 120 days after planting of crop (first cut *i.e.*, July) and second harvest at 120 days after first harvesting (second cut *i.e.*, during October). Tillers were harvested 10-15 cm from the ground from randomly marked plants in the plot and yield attributes were analyzed.

Table 1. Treatment details

Treatment	Treatment details
T1	NPK @80:60:60 kg ha^{-1}
T2	NPK @100:60:60 kg ha^{-1}
T3	NPK @120:60:60 kg ha^{-1}
T4	NPK @80:50:50 kg ha^{-1}
T5	NPK @100:50:50 kg ha^{-1}
T6	NPK @120:50:50 kg ha^{-1}
T7	NPK @80:40:40 kg ha^{-1}
T8	NPK @100:40:40 kg ha^{-1}
T9	NPK @120:40:40 kg ha^{-1}
T10	FYM10 tonnes ha^{-1}
T11	Control (without fertilizer)

Determination of essential oil content

Fresh leaves and immature stems of lemongrass were harvested from randomly selected plants. These were cut into 3-5 cm pieces for essential oil extraction using a Clevenger apparatus. The sample was placed in a flask with distilled water, was boiled at 98°C. After two and half hour of extraction, the essential oil was collected in a burette and measured directly and finally recorded. The projected essential oil yield was calculated per hectare based on projected fresh herbage yield per plot assuming 80% of the area occupied by lemongrass. The maximum oil content was observed between 117 and 125 days after planting (Prins *et al.*, 2016). Considering these findings, harvesting at 120 days after planting and ratooning was imposed.

Observation and analysis

For the observation of morphological traits, random plants were selected and tagged within each experimental plot. The parameters recorded included plant height, number of tillers per clump, number of leaves per clump, fresh herbage yield, dry yield and essential oil content.

Economics of lemongrass cultivation

The total cost of production (COP) and gross returns (GR) were calculated to assess the economic viability of lemongrass cultivation. Inputs included Urea (46% N) at Rs. 8.5 kg^{-1}, SSP (16% P2O5) at Rs. 15 kg^{-1}, MOP (60% K2O) at Rs. 22 kg^{-1}, planting material at Rs. 2 slip^{-1}, labour at Rs. 328.00 for an 8-hour day and oil selling price was Rs. 2000 liter^{-1} average market price (IndiaMART, 2023). For working the gross return (GR) selling price of essential oil as Rs. 2000 liter^{-1} was considered while net return (NR) was calculated as the difference between Gross Return (GR) and cost of production (COP). The benefit cost ratio was calculated by dividing gross returns (GR) with total expenditure.

Statistical analysis

The recorded data were subjected to statistical analysis following the principles of a Randomized Block Design (RBD) as described by Gomez and Gomez (1984). The significance of treatment effects was evaluated using Fisher and Snedecor's F-test at the 5% probability level. The Least Significant Difference (LSD) at the same level of significance was calculated using critical values obtained from the statistical tables of Fisher and Yates (1974). Additionally, Python programming language was employed for advanced data analysis, including correlation matrix computation and principal component analysis (PCA).

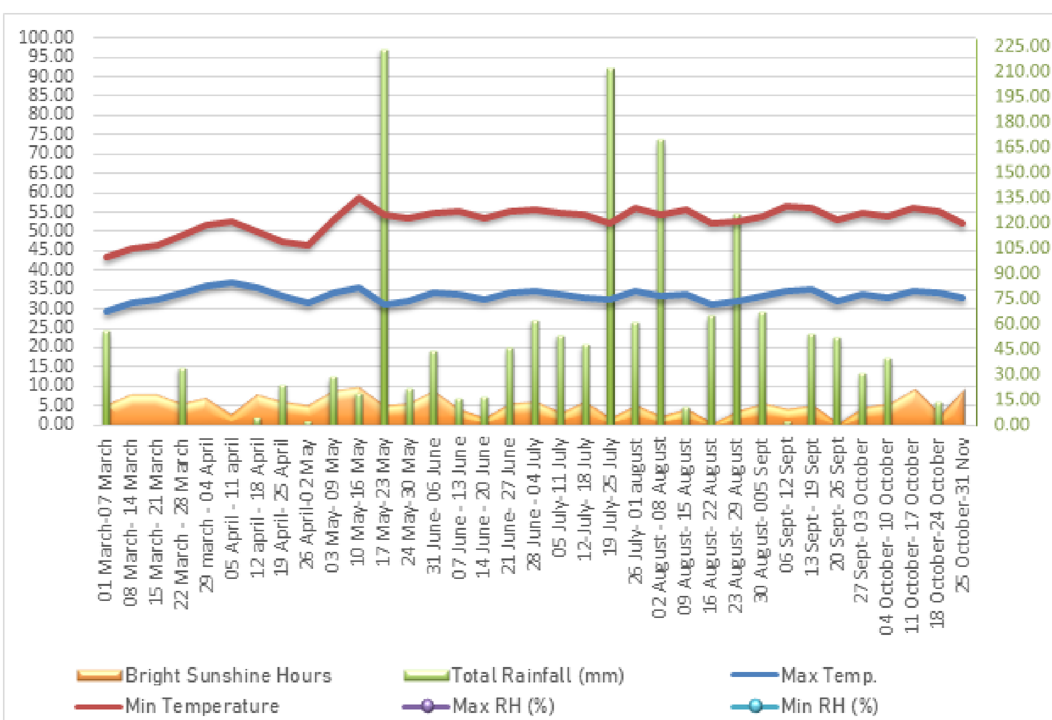

Fig. 1. Weekly weather data of the experimental site during 2023.

Results and discussion

The data (Table 2) reflects the influence of different nutrient management treatments on key growth parameters of *Cymbopogon flexuosus* (cv. Krishna) over two consecutive cuttings. Among the treatments, treatment-3 NPK @120:60:60 kg ha^{-1} consistently recorded the highest plant height (196.6 cm and 198.4 cm), number of tillers per clump (58.0 and 60.3) and number of leaves per clump (310.3 and 342.0) in the first and second cutting, respectively. These values were significantly superior and statistically at par with treatment-2 NPK @ 100:60:60 kg ha^{-1} and treatment-6 NPK @120:50:50 kg ha^{-1} for most parameters, indicating comparable performance. In contrast, treatment-11 control (without fertilizer) showed the poorest growth across all parameters. These results suggest that treatment-3 NPK @ 120:60:60 kg ha^{-1} along with treatment-6 NPK @ 120:50:50 kg ha^{-1} and treatment-2 NPK @ 100:60:60 kg ha^{-1}, provided optimal nutrient support to enhance vegetative growth, while treatment-11 control (without fertilizer) was insufficient in promoting desirable plant development. The superior growth observed under higher NPK levels can primarily be attributed to the role of nitrogen in promoting vigorous vegetative growth, as nitrogen is a key constituent of chlorophyll, amino acids, proteins and nucleic acids. Adequate nitrogen supply enhances cell division, cell elongation and leaf area development, resulting in taller plants, more tillers and a higher number of leaves per clump. Phosphorus, on the other hand, supports root development and energy transfer (ATP), while potassium regulates enzyme activation, stomatal function, and translocation of photosynthates, together ensuring balanced and efficient plant growth. The combined and balanced supply of N, P and K in treatment-3 NPK 120:60:60 kg ha^{-1}, treatment-2 NPK @ 100:60:60 kg ha^{-1} and treatment-6 NPK @ 120:50:50 kg ha^{-1} therefore had an optimal nutrition, leading to improved vegetative growth over both cuttings.

Similar responses to increased and balanced fertilization have been widely reported in aromatic and field crops, where adequate nutrient availability enhances photosynthetic efficiency, biomass accumulation and tillering capacity. In contrast, the control treatment-11 *i.e.*, treatment without fertilizer recorded the lowest values for all growth parameters, which can be explained by poor nutrient availability in the soil, leading to restricted photosynthesis, reduced cell division and limited vegetative growth.

The farm yard manure treatment -10 FYM @10 t ha^{-1} showed better growth than the control but remained inferior to the inorganic fertilizer treatments. This indicates that FYM alone, although beneficial, releases nutrients slowly and in limited quantities, which may not be sufficient to meet the high nutrient demand of a fast-growing, high-biomass crop like lemongrass during peak growth periods. However, the improvement over control suggests that FYM contributed to better soil physical properties, microbial activity and gradual nutrient supply, which supported moderate enhancement in plant height, tiller number and leaf production. This agrees with the general understanding that organic manures improve soil health and nutrient availability over time, but their effect is usually less immediate and less pronounced than readily available inorganic fertilizers in short-term growth responses.

Overall, the results indicate that balanced and adequate nitrogen-based fertilization particularly treatment-3 NPK @ 120:60:60 kg ha^{-1} and treatment -2 NPK@ 100:60:60 kg per hectare was crucial for maximizing vegetative growth of Cymbopogon flexuosus, while sole application of FYM, though beneficial, was insufficient to achieve comparable growth levels. The marked superiority of fertilized treatments over the control further confirms that nutrient availability a key limiting factor governing growth and development in lemongrass under the present experimental conditions. Saini *et al*., (2018) also noted that increased nitrogen levels positively influenced plant height in lemongrass. Singh (1999) also reported a significant increase in plant height with higher nitrogen applications, highlighting nitrogen's essential role in vegetative growth. Singh *et al*., (2008) and Gajbhiye *et al*., (2013) similarly documented enhanced plant height with higher doses of fertilizers. Additionally, Thomas *et al*., (1990) observed that tiller production improved under elevated nitrogen application. Gajbhiye *et al*., (2013) also reported that the inorganic fertilizers led significant increase in the number of leaves per clump. Furthermore, the number of leaves per clump was found to be positively correlated with the number of tillers, reaffirming the interconnected nature of vegetative growth parameters in lemongrass.

Application of fertilizers NPK@ 120:60:60 kg ha^{-1} (T3) recorded significantly higher fresh herbage yield (16.5 and 17.9 t ha^{-1}), dry herbage yield (4.7 and 4.9 t ha^{-1}), and essential oil yield (72.4 and 81.1 litres ha^{-1}) during the first and second seasons, respectively (Table 3). These results were statistically superior and at par with T6 (NPK@ 120:50:50 kg ha^{-1}) and T2 (NPK@ 100:60:60 kg ha^{-1}) for most parameters, indicating a comparable positive effect of these treatments on biomass accumulation and oil production. The highest oil content (0.44% and 0.45%), was also observed in T3 (NPK@120: 60:60 kg ha^{-1}) which was significantly superior to other treatments and statistically at par with T6 in both harvests. Conversely, the lowest yields and oil content were consistently recorded in control (without fertilizer), suggesting suboptimal growth conditions or inadequate nutrient availability. These findings suggest that T3 followed closely by T6 and T2 provided the most favourable conditions for enhancing both biomass and essential oil yield in lemongrass, underscoring the importance of nutrient strategies for optimizing productivity in this aromatic crop.

Table 2. Impact of nutrient management of crop parameters in lemongrass

Treatment	Plant height (cm)		Number of tillers/ clump		Number of leaves/clump	
	1st cut (Jul)	2nd cut (Oct)	1st cut (Jul)	2nd cut (Oct)	1st cut (Jul)	2nd cut (Oct)
Treatment 1 -NPK @80:60:60 kg ha^{-1}	194.7	196.7	52.3	56.3	279.6	319.6
Treatment 2 - NPK @100:60:60 kg ha^{-1}	195.4	196.8	55.6	57.6	297.6	327.3
Treatment 3- NPK @120:60:60 kg ha^{-1}	196.6	198.4	58.0	60.3	310.3	342.0
Treatment 4 - NPK @ 80:50:50 kg ha^{-1}	189.9	194.3	51.6	53.0	275.0	300.6
Treatment 5 - NPK @ 100:50:50 kg ha^{-1}	192.1	195.1	55.0	55.6	294.3	316.3
Treatment 6- NPK @120:50:50 kg ha^{-1}	194.7	197.3	54.6	57.3	292.6	325.0
Treatment 7 - NPK @80:40:40kg ha^{-1}	181.3	191.1	49.6	52.0	264.0	294.0
Treatment 8 - NPK @100:40:40 kg ha^{-1}	186.0	193.6	50.6	52.6	269.6	298.3
Treatment 9- NPK @ 120:40:40 kg ha^{-1}	190.6	196.5	53.3	55.0	284.6	312.3
Treatment 10- FYM @ 10 t ha^{-1}	179.7	184.5	38.6	48.0	205.3	272.0
Treatment 11- Control (without fertilizer)	174.8	176.2	35.3	40.0	188.3	227.3
S. Em (±)	3.203	2.134	1.486	1.406	9.501	8.432
C. D. (5%)	9.517	6.34	4.415	4.176	28.225	25.05

The improvement in yield components and essential oil content may be attributed to the adequate availability of nitrogen, phosphorus, and potassium, which are essential for both vegetative growth and secondary metabolite production. Gajbhiye *et al*., (2013), who also observed higher herbage and oil yields in lemongrass under higher chemical fertilizer application. Similarly, Singh *et al.*, (2008) highlighted the role of nitrogen in increasing essential oil content, which aligns with the present results. The superiority of T3 in all yield parameters reaffirms the importance of NPK fertilizer application for maximizing the economic returns from lemongrass cultivation. The positive response may be attributed to adequate nitrogen availability enhancing cell division and elongation, while phosphorus and potassium supported root development and nutrient translocation.

Table 3. Impact of nutrient management on yield parameters of lemongrass

Treatments	Fresh herbage yield (t ha^{-1})		Dry herbage yield (t ha^{-1})		Essential oil yield (L ha^{-1})		Oil %	Oil %
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
	(Jul)	(Oct)	(Jul)	(Oct)	(Jul)	(Oct)	(Jul)	(Oct)
Treatment 1 -NPK @80:60:60 kg ha^{-1}	14.3	15.3	3.9	4.0	60.9	65.5	0.42	0.43
Treatment 2 -NPK @100:60:60 kg ha^{-1}	15.6	16.5	4.4	4.4	65.6	70.3	0.42	0.43
Treatment 3- NPK @120:60:60 kg ha^{-1}	16.5	17.9	4.7	4.9	72.4	81.1	0.44	0.45
Treatment 4-NPK@ 80:50:50 kg ha^{-1}	13.0	14.1	3.0	3.7	53.4	59.7	0.41	0.42
Treatment5-NPK @ 100:50:50 kg ha^{-1}	13.6	15.1	4.0	4.0	56.4	62.8	0.41	0.42
Treatment 6- NPK @120:50:50 kg ha^{-1}	15.9	17.1	4.3	4.4	70.2	75.6	0.44	0.44
Treatment 7- NPK @80:40:40 kg ha^{-1}	13.4	13.0	3.7	3.8	55.0	54.5	0.41	0.42
Treatment 8- NPK @100:40:40 kg ha^{-1}	14.2	13.5	3.7	3.8	58.2	57.3	0.41	0.42
Treatment 9-NPK @ 120:40:40 kg ha^{-1}	15.3	16.8	4.0	4.1	64.5	72.7	0.42	0.43
Treatment 10- FYM @ 10 t ha^{-1}	12.7	13.0	3.2	3.3	52.5	56.0	0.41	0.43
Treatment 11- Control (without fertilizer)	6.6	6.7	1.5	1.6	25.0	27.2	0.38	0.40
S. Em (±)	0.45	0.37	0.22	0.18	1.89	2.01	0.031	0.021
C. D. (5%)	1.36	1.12	0.67	0.54	5.62	5.97	0.01	0.007

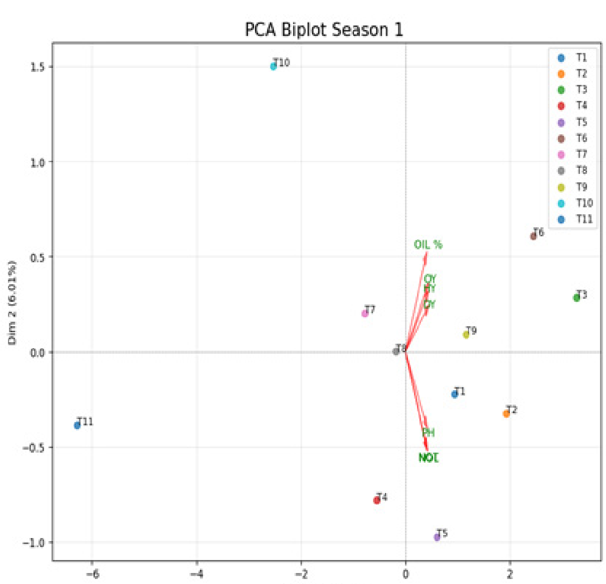

Fig. 2a. Principal component analysis of different treatments in relation to traits (Season 1)

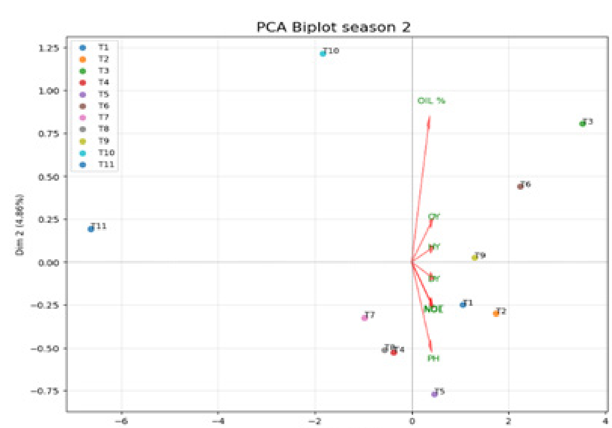

Fig. 2b. Principal component analysis of different treatments in relation to traits (Season 2)

The Principal Component Analysis (PCA) biplot (fig.-2a and 2b) provides a clear and insightful visualization of the associations between treatments and the measured agronomic traits, represented as vectors. The spatial distribution of treatments on the plot is determined by their respective scores along two principal components: Dimension 1 (Dim 1) on the X-axis and Dimension 2 (Dim 2) on the Y-axis (Fig. 2a & 2b). In the first season, Dim 1 accounted for 90.78% of the total variability, while in the second season it explained an even higher proportion, at 93.88%. Dim 2 contributed an additional 6.01% and 4.86% to the variation in the respective seasons.

Among the measured traits, oil %, fresh herbage yield (HY), dry yield (DY) and essential oil yield (OY) were strongly aligned with Dim 2, suggesting their dominant role in driving yield-related variation across treatments. In contrast, plant height (PH), number of tillers (NOT), and number of leaves (NOL) clustered below the origin, indicating a comparatively lower influence on treatment differentiation in the PCA space. Treatments-3,6 and 9 were distinct from others, demonstrating strong and consistent performance across both growing seasons. Their position on the biplot highlights their superior contribution to key yield traits, reinforcing their effectiveness under the studied conditions.

Correlation analysis of traits

Pearson's correlation analysis was performed to explore the relationships among various morphological and yield-related traits. The correlation matrix is illustrated in Fig. 3a & 3b. The results showed a strong positive correlation between plant height (PH) and number of tillers (NOT), with a coefficient of 0.92. Furthermore, traits such as number of tillers (NOT), number of leaves (NOL), herbage yield (HY), dry yield (DY), oil percentage (OP), and oil yield (OY) were all positively correlated with one another, indicating a close association among these key yield-contributing factors.

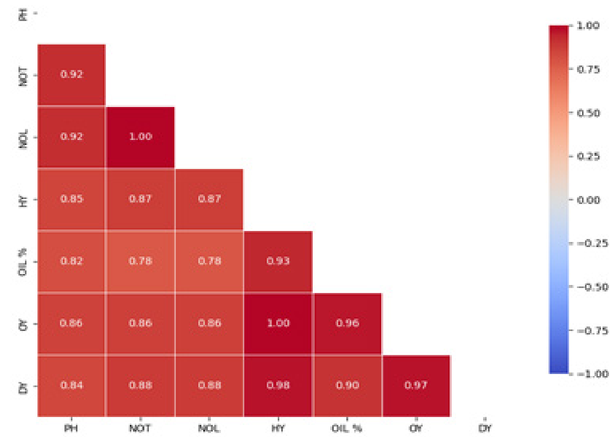

Fig. 3a. Correlation matrix of traits – Season 1

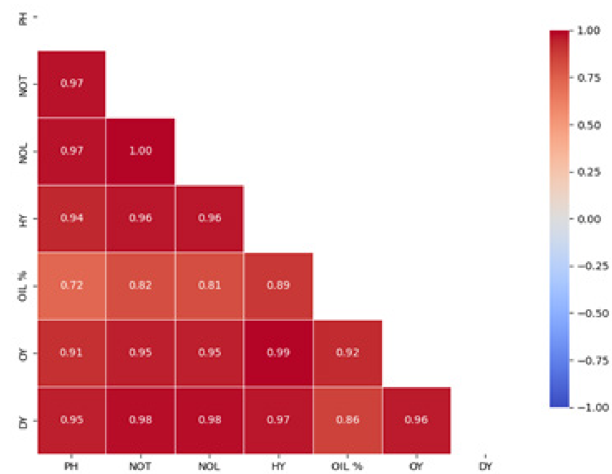

Fig. 3b. Correlation matrix of traits – Season 2

Based on the economic analysis of lemongrass cultivation under different fertilizer treatments across two harvests/cuts (July and October), it was observed that higher NPK levels significantly enhanced oil yield and profitability (Tables 4 and 5). Among all treatments, NPK @120:60:60 kg ha^{-1} (Treatment-3) consistently recorded the highest oil yield and economic return in both cuts, with a net profit of Rs. 75,696.8 and B:C ratio of 2.09 in first harvest, which increased to Rs. 1,23,631 with a B:C ratio of 4.19 in second harvest. The increased benefit in the second harvest can be attributed to reduced cost of cultivation, likely due to residual nutrient effect and improved plant establishment. Treatments with no NPK

Table 4. Economics of lemongrass cultivation for cut 1 (July)

Treatments	Oil yield (%)	Oil price (Rs /l)	Gross return (Rs)	Total Expenditure (Rs)	Net profit (Rs)	B:C ratio
Treatment 1- NPK @80:60:60 kg ha^{-1}	60.92	2000	121840	68525.4	53314.6	1.78
Treatment 2- NPK @100:60:60 kg ha^{-1}	65.63	2000	131260	68894.3	62365.7	1.91
Treatment 3- NPK @120:60:60 kg ha^{-1}	72.48	2000	144960	69263.2	75696.8	2.09
Treatment 4- NPK @ 80:50:50 kg ha^{-1}	53.45	2000	106900	67119.2	39780.8	1.59
Treatment 5- NPK @ 100:50:50 kg ha^{-1}	56.47	2000	112940	67488.1	45451.9	1.67
Treatment 6- NPK @120:50:50 kg ha^{-1}	70.20	2000	140400	67857.0	72543.0	2.07
Treatment 7- NPK @80:40:40 kg ha^{-1}	55.08	2000	110160	65712.9	44447.1	1.68
Treatment 8- NPK @100:40:40 kg ha^{-1}	58.27	2000	116540	66081.8	50458.2	1.76
Treatment 9- NPK @ 120:40:40 kg ha^{-1}	64.55	2000	129100	66450.7	62649.3	1.94
Treatment 10- FYM @ 10 t ha^{-1}	52.5	2000	105000	68612.3	36387.7	1.53
Treatment 11- Control (without fertilizer)	25.06	2000	50120	58612.3	-8492.3	0.86

Table 5. Economics of lemongrass cultivation for cut 2 (October)

Treatment	Oil yield (%)	Oil price (Rs /l)	Gross return (Rs)	Total Expenditure (Rs)	Net profit (Rs)	B:C ratio
Treatment 1- NPK @80:60:60 kg ha^{-1}	65.57	2000	131140	38011.4	93128.6	3.45
Treatment 2 - NPK @100:60:60 kg ha^{-1}	70.37	2000	140740	38380.3	102360	3.67
Treatment 3- NPK @120:60:60 kg ha^{-1}	81.19	2000	162380	38749.2	123631	4.19
Treatment 4- NPK @ 80:50:50 kg ha^{-1}	59.72	2000	119440	36605.2	82834.8	3.26
Treatment 5- NPK @ 100:50:50 kg ha^{-1}	62.85	2000	125700	36974.1	88725.9	3.40
Treatment 6- NPK @120:50:50 kg ha^{-1}	75.67	2000	151340	37343.0	113997	4.05
Treatment 7- NPK @80:40:40 kg ha^{-1}	54.50	2000	109000	35198.9	73801.1	3.10
Treatment 8- NPK @100:40:40 kg ha^{-1}	57.38	2000	114760	35567.8	79192.2	3.23
Treatment 9- NPK @ 120:40:40 kg ha^{-1}	72.76	2000	145520	35936.7	109583	4.05
Treatment 10- FYM @ 10 t ha^{-1}	56.09	2000	112180	38098.3	74081.7	2.94
Treatment 11- Control (without fertilizer)	27.23	2000	54460	28098.3	26361.7	1.94

doses (control) resulted in comparatively lower returns, with a negative net profit in 1st cut and the lowest B:C ratio in both cuts. These findings highlight the importance of balanced NPK fertilization for maximizing the economic returns from lemongrass cultivation.

Conclusion

Based on the findings, T3 NPK @ 120:60:60 kg ha^{-1}) consistently outperformed all other treatments in terms of growth, yield and also resulted in better cost–benefit (C:B) ratio. In contrast, the control treatment (without fertilizer application) recorded the lowest oil content and oil yield. The results further confirmed a direct and significant relationship between fresh herbage yield and essential oil yield, which ultimately governs market value and profitability. Overall, the study clearly demonstrates that an optimum dose of NPK fertilization plays a critical role in maximizing both biomass production and essential oil yield in lemongrass.

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