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Determination of an Effective Inorganic Fertilizer Regime for Lemongrass Cultivation under Climate Change Conditions in Tan Phu Dong, Dong Thap Province, Vietnam

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ABSTRACT: This study aimed to determine an effective inorganic fertilizer regime for lemongrass (*Cymbopogon citratus*) under climate change conditions in Tan Phu Dong, Dong Thap Province, Vietnam. Lemongrass production in coastal and low-lying areas is increasingly challenged by soil salinity, nutrient imbalance, and unstable weather patterns associated with climate change, making it difficult to optimize fertilizer management for sustainable yield. A randomized complete block design with nine fertilizer treatments was conducted on a background application of 2,000 kg ha^{-1} of microbial organic fertilizer, with three replications. Results showed that fertilizer regimes significantly affected plant growth, yield, and economic return. The 138–48–60 (N–P_2O_5–K_2O) treatment produced superior performance, with the highest plant height and tiller number at 120 and 180 days after transplanting, and the highest harvested biomass yield (58.50 t ha^{-1}). This treatment also achieved the highest economic profit (175 million VND ha^{-1}). In contrast, the control treatment (92–48–60) recorded the lowest productivity and economic efficiency. This study contributes practical evidence for optimizing inorganic fertilizer regimes combined with organic inputs, providing a climate-adaptive nutrient management strategy to enhance productivity, profitability, and sustainability of lemongrass cultivation in the Mekong Delta.

Keywords: lemongrass, inorganic fertilizer, yield, nutrient management, climate adaptation.

INTRODUCTION

Lemongrass (*Cymbopogon citratus*) is an important spice and medicinal crop in Vietnam, widely used in the food industry, pharmaceutical applications, and essential oil production. The crop exhibits strong adaptability to tropical conditions; however, productivity and oil quality are strongly influenced by soil fertility and nutrient management. Previous studies have demonstrated that balanced fertilization, combining organic amendments with inorganic NPK fertilizers, plays a crucial role in improving plant height, tiller formation, biomass production, and essential oil yield (Sharma *et al*., 2017; Nguyen & Tran 2022).

Climate change has increasingly affected agricultural production in the Mekong Delta, where irregular rainfall, drought, salinity intrusion, and soil moisture fluctuations directly influence crop productivity (Le & Vo 2020). Tan Phu Dong is one of the major lemongrass cultivation areas but is increasingly exposed to prolonged drought, declining soil fertility, and soil degradation. Nutrient-poor soils reduce fertilizer use efficiency, often forcing farmers to increase fertilizer inputs, which raises production costs and accelerates soil deterioration.

International studies have shown that optimizing inorganic fertilizer regimes on soils amended with organic fertilizers can improve soil properties, enhance nutrient uptake, increase yield, and strengthen plant tolerance to environmental stress (Kumar *et al*., 2019). Organic fertilizers improve soil structure and nutrient retention, thereby enhancing the effectiveness of mineral fertilizers. However, studies on lemongrass nutrient management in Vietnam remain limited, particularly those evaluating inorganic fertilizer regimes applied on an organic fertilizer background under climate-affected riverine soils.

Therefore, this study was conducted to determine an appropriate inorganic fertilizer regime for lemongrass cultivation in Tan Phu Dong. The objective was to evaluate the effects of different fertilizer formulas on plant growth, yield, and climate adaptability, thereby supporting improved fertilizer recommendations, reduced production costs, and sustainable agricultural development.

MATERIALS AND METHODS

Experimental site and duration. The experiment was conducted from January to June 2025 in Ba Tien 1 hamlet, Phu Dong commune, Tan Phu Dong district, Tien Giang Province (currently Tan Phu Dong commune, Dong Thap Province), Vietnam.

Plant material. The local lemongrass cultivar (*Cymbopogon citratus*) was used.

Experimental design. The experiment was arranged in a randomized complete block design with nine fertilizer treatments and three replications. Each plot covered 20 m², with a total experimental area of 540 m². Planting density was 40,000 plants ha^{-1}. All treatments received a basal application of microbial organic fertilizer at 2,000 kg ha^{-1}.

Fertilizer treatments

Treatment No.	N - P_2O_5 - K_2O (kg/ha)	Equivalent fertilizer rates
1	92 - 48 - 60 (Control)	200 kg ure + 300 kg phosphate fertilizer+100 kg potassium chloride ha^{-1}
2	115 - 48 - 60	250 kg ure + 300 kg phosphate fertilizer+100 kg potassium chloride ha^{-1}
3	115 - 48 - 90	250 kg ure + 300 kg phosphate fertilizer+150 kg potassium chloride ha^{-1}
4	115 - 64 - 60	250 kg ure + 400 kg phosphate fertilizer+100 kg potassium chloride ha^{-1}
5	115 - 64 - 90	250 kg ure + 400 kg phosphate fertilizer+150 kg potassium chloride ha^{-1}
6	138 - 48 - 60	300 kg ure + 300 kg phosphate fertilizer+100 kg potassium chloride ha^{-1}
7	138 - 48 - 90	300 kg ure + 300 kg phosphate fertilizer+150 kg potassium chloride ha^{-1}
8	138 - 64 - 60	300 kg ure + 400 kg phosphate fertilizer+100 kg potassium chloride ha^{-1}
9	138 - 64 - 90	300 kg ure + 400 kg phosphate fertilizer+150 kg potassium chloride ha^{-1}

Fertilizer application schedule

Basal: all organic fertilizer and phosphorus
20–25 DAT: 25% urea
50–55 DAT: 50% urea + 50% KCl
80–85 DAT: remaining 25% urea + 50% KCl

Data collection

Growth parameters were recorded following QCVN 01-189:2019/BNNPTNT. Ten clumps per plot were randomly selected and tagged to measure plant height and tiller number at 40, 80, 120 DAT and at first harvest. Yield components included stem length, stem diameter, fresh biomass per clump, and stem weight after leaf removal.

Theoretical stem yield (t ha^{-1}) was calculated based on stem weight per clump and planting density. Harvested yield was determined from the total stem weight per plot and converted to t ha^{-1}.

Pest and disease incidence (mealybugs, leaf spot, root rot) was monitored following the standard field pest survey procedure of the Plant Protection Department.

Statistical analysis. Data were analyzed using SPSS software. Treatment means were compared using Duncan's multiple range test.

RESULTS AND DISCUSSION

Plant height

Plant height of lemongrass increased progressively from 40 to 180 days after transplanting (DAT) across all fertilizer treatments (Table 1), indicating vigorous vegetative growth under intensive cultivation. No significant differences were observed at the early stage (40–80 DAT), where plant height ranged from 86.3–88.3 cm and 106.0–107.9 cm, respectively. This suggests that early plant growth was primarily determined by transplant establishment, root recovery, and nutrient reserves in the planting material rather than fertilizer treatments, which agrees with previous reports for aromatic perennial crops showing delayed nutrient response until canopy establishment (De Silva *et al.*, 2020). Significant treatment effects appeared at 120 DAT ($p < 0.05$). Treatment 6 produced the tallest plants (129.3 cm), significantly higher than most treatments (120.9–122.9 cm), while Treatment 8 (126.1 cm) was statistically comparable with Treatment 6. This superiority persisted at 180 DAT, with Treatments 6 and 8 reaching 133.3 cm and 130.1 cm, respectively, compared with 124.8–126.9 cm in the remaining treatments. The emergence of treatment differences at later stages indicates that fertilizer supply became increasingly important once rapid vegetative growth and biomass accumulation began, which is consistent with findings reported by Kumar *et al.* (2021) ; Rahman *et al.* (2022). Adequate nitrogen availability is known to enhance leaf expansion, chlorophyll synthesis, and canopy development, whereas potassium plays a central role in stomatal regulation, photosynthetic efficiency, and assimilate transport (Singh *et al.*, 2016; FAO, 2018). Recent studies have further confirmed that optimized N and K fertilization significantly improves vegetative growth and biomass accumulation in lemongrass under tropical conditions (Yadav *et al.*, 2023; Tran *et al.*, 2023). Therefore, the greater plant height observed under Treatments 6 and 8 likely reflects improved nutrient availability supporting sustained vegetative vigor and higher biomass production potential in lemongrass cultivation systems. This trend is in line with previous reports emphasizing the importance of balanced and continuous nutrient supply for maintaining long-term growth performance in aromatic crops (Patel *et al.*, 2020).

Table 1: Effect of fertilizer regimes on plant height of lemongrass.

Treatment	Plant height			
	40 DAT	80 DAT	120 DAT	180 DAT
1	86.60	106.0	121.5b	125.5b
2	86.73	106.3	120.9b	124.8b
3	87.27	107.9	121.2b	125.2b
4	88.33	106.5	121.3b	125.3b
5	88.20	106.7	122.9b	126.9b
6	87.67	106.9	129.3a	133.3a
7	87.20	106.7	120.9b	124.8b
8	87.07	107.2	126.1ab	130.1ab
9	86.33	107.9	121.9b	125.7b
Mean	ns	ns	*	*
CV (%)	2.04	3.66	3.64	2.34

Within the same column, values followed by the same letter are not significantly different. ns = not significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$; DAT = days after transplanting.

Number of tillers

The number of tillers per lemongrass clump increased continuously from 40 to 180 days after transplanting (DAT) across all fertilizer treatments (Table 2), indicating strong vegetative propagation under intensive cultivation conditions. At the early growth stage (40–80 DAT), the number of tillers ranged from 7.20–8.40 tillers clump^{-1} at 40 DAT and increased to 15.80–17.93 tillers clump^{-1} at 80 DAT. Although slight numerical differences were observed among treatments, these differences were not statistically significant (ns), suggesting that early tiller formation was relatively uniform and mainly governed by initial rhizome establishment and plant adaptation rather than fertilizer inputs. Similar observations were reported by Kumar *et al*. (2017), who noted that early tiller differentiation in lemongrass is largely influenced by initial plant vigor and environmental conditions rather than external nutrient supply. Significant treatment effects emerged from 120 DAT onward (**$p < 0.01$). At 120 DAT, Treatment 6 produced the highest tiller number (26.47 tillers clump^{-1}), significantly exceeding Treatment 1 (21.93 tillers clump^{-1}) and most other treatments (22.27–24.80 tillers clump^{-1}). This superiority was maintained at 180 DAT, where Treatment 6 reached the maximum value (30.27 tillers clump^{-1}), followed by Treatment 3 (29.33) and Treatment 9 (29.07), whereas Treatment 1 recorded the lowest value (23.27). The stronger fertilizer response during the mid-to-late growth stages indicates that nutrient availability became increasingly important once active tiller proliferation and biomass accumulation began. Adequate nitrogen supply promotes vegetative branching and shoot formation, while balanced potassium nutrition enhances physiological efficiency and assimilate translocation, thereby supporting sustained tiller production and canopy development (Pandey *et al*., 2018; Choudhary *et al*., 2020). A greater number of tillers is a key biological trait directly associated with higher biomass yield and harvest productivity in lemongrass cultivation systems.

Table 2: Effect of fertilizer regimes on Number of tillers.

Treatment	Number of tillers			
	40 DAT	80 DAT	120 DAT	180 DAT
1	7.20	15.80	21.93c	23.27c
2	7.80	16.67	23.60bc	26.87bc
3	7.87	17.87	24.20b	29.33bc
4	7.40	16.47	22.27bc	24.93bc
5	8.27	17.00	22.87bc	26.00bc
6	8.20	17.93	26.47a	30.27a
7	8.13	17.47	24.67b	28.07bc
8	8.40	17.07	24.80b	28.27bc
9	7.47	17.80	23.07bc	29.07bc
Mean	ns	ns	**	**
CV (%)	9.60	5.50	4.07	4.20

Within the same column, values followed by the same letter are not significantly different. ns = not significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$: DAT = days after transplanting.

Effect of fertilizer regimes on yield components of lemongrass

Yield components of lemongrass were markedly influenced by different fertilizer regimes (Table 3). Significant differences were observed in leaf-stem biomass, stem weight, and stem diameter, whereas commercial plant height was not significantly affected. Leaf-stem biomass ranged from 1.75 to 2.15 kg per 10 clumps. The 138–48–60 treatment produced the highest biomass (2.15 kg), significantly exceeding the control (92–48–60; 1.75 kg) and several other treatments. Treatments receiving higher or more balanced nutrient inputs generally produced greater biomass, indicating improved nutrient utilization and enhanced vegetative growth capacity. This finding is consistent with recent studies showing that optimized NPK fertilization significantly enhances biomass accumulation in lemongrass and other aromatic grasses under tropical conditions (Kumar *et al.*, 2021; Rahman *et al.*, 2022; Yadav *et al.*, 2023). A similar trend was observed for stem weight, which varied from 0.95 to 1.19 kg per 10 clumps. The 138–48–60 treatment again recorded the highest value (1.19 kg), statistically comparable with 115–48–90 (1.18 kg) but significantly higher than most other treatments. The lowest stem weight occurred in the control (0.95 kg), suggesting reduced assimilate accumulation and weaker pseudo-stem development. Stem weight has been identified as a key indicator of nutrient conversion efficiency into harvestable biomass in lemongrass production systems (Ahmed *et al.*, 2019), and recent studies further confirmed that increased nitrogen and potassium availability improves assimilate partitioning and structural biomass formation in aromatic crops (Patel *et al.*, 2020; Singh *et al.*, 2021).

Commercial plant height ranged from 48.60 to 52.33 cm and did not differ significantly among treatments, indicating that this trait is relatively stable and less responsive to fertilizer regimes compared with biomass-related traits. Similar findings were reported by Rahman *et al.* (2018), who observed limited variation in commercial stem height compared with other yield components in aromatic grasses. More recent studies also support this observation, indicating that plant height in lemongrass is largely genetically controlled and less sensitive to short-term nutrient fluctuations compared with yield-related traits (Tran *et al.*, 2023; Yadav *et al.*, 2023).

In contrast, stem diameter showed significant variation, ranging from 17.54 to 21.67 mm. The 138–48–60 treatment produced the largest stem diameter (21.67 mm), significantly higher than the control (17.54 mm). Higher and more balanced fertilizer inputs generally resulted in thicker stems, reflecting stronger pseudo-stem growth and improved biomass accumulation. Stem diameter is considered an important determinant of commercial quality and economic value in lemongrass cultivation (Mishra *et al.*, 2020). This result is further supported by recent findings indicating that adequate potassium supply enhances cell wall development, turgor maintenance, and stem thickening, thereby improving marketable yield and structural stability (Kumar *et al.*, 2021; Rahman *et al.*, 2022).

Overall, the results demonstrate that appropriate fertilizer management not only increases vegetative biomass but also significantly improves key yield-determining traits, particularly stem weight and diameter, thereby contributing to higher productivity and production efficiency in lemongrass cultivation systems. These findings align with recent reports emphasizing the role of balanced fertilization and integrated nutrient management in enhancing both yield and quality of aromatic crops under intensive production systems (Patel *et al.*, 2020; Tran *et al.*, 2023; Yadav *et al.*, 2023).

Table 3: Effect of fertilizer regimes on yield components of lemongrass.

Treatment	Mean leaf–stem biomass (kg)	Mean stem weight (kg)	Commercial plant height (cm)	Stem diameter (mm)	Theoretical yield (t ha^{-1})	Harvested stem yield (t ha^{-1})
1	1.75c	0.95b	48.60	17.54c	38.00c	23.50c
2	1.86c	1.03ab	51.07	18.34bc	41.07bc	26.67bc
3	2.06ab	1.18a	50.33	20.59ab	47.60ab	31.83b
4	1.81c	0.99b	49.60	19.12b	39.47bc	26.33bc
5	1.95bc	1.08ab	52.20	19.25b	43.33bc	26.33bc
6	2.15a	1.19a	51.73	21.67a	47.73a	35.00a
7	1.80c	0.97b	50.13	19.73b	38.67bc	24.67bc
8	1.79c	0.96b	52.33	19.42b	38.53bc	25.67bc
9	1.94bc	1.07ab	49.33	19.86b	42.93bc	26.00bc
Mean	*	*	ns	*	*	*
CV (%)	6.0	7.39	3.52	4.71	3.12	3.21

Within the same column, values followed by the same letter are not significantly different. ns = not significant; * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$; DAT = days after transplanting.

Fertilizer regimes significantly affected both theoretical and harvested stem yield of lemongrass (Table 3, $p < 0.05$). Theoretical yield ranged from 38.00 to 47.73 t ha^{-1}, while harvested yield varied from 23.50 to 35.00 t ha^{-1}. The 138–48–60 treatment produced the highest yields (47.73 and 35.00 t ha^{-1}, respectively), significantly exceeding the control (92–48–60), which recorded the lowest values (38.00 and 23.50 t ha^{-1}). The superior performance of the 138–48–60 regime suggests that adequate nitrogen combined with balanced phosphorus and potassium enhanced vegetative growth, photosynthetic capacity, and biomass accumulation.

Similar improvements in lemongrass yield under balanced NPK fertilization have been reported previously (El-Mahrouk *et al.*, 2018; Singh *et al*., 2020). In contrast, less balanced nutrient supply resulted in lower productivity, indicating reduced nutrient use efficiency (Mahmoud *et al*., 2023).

Overall, balanced fertilizer management plays a key role in maximizing stem yield and production efficiency in lemongrass cultivation.

Effect of fertilizer regimes on pest and disease incidence

During all observation periods, pest and disease incidence, including mealybugs, leaf spot, and root rot, was monitored and assessed following the standard field survey procedures for crop pest detection issued by the Plant Protection Department. However, no pest or disease occurrence was recorded in any treatment throughout the experimental period. The absence of major pest and disease infestation may be associated with appropriate field management practices and favorable cultivation conditions, which likely helped suppress the development and spread of potential pests and pathogens in the lemongrass field.

Soil analysis

Soil physicochemical properties showed moderate changes after the experiment (Table 4). Soil pH (H_2O) slightly increased (5.81→6.11), indicating improved conditions for nutrient availability, whereas pH (KCl) decreased, possibly due to increased exchangeable acidity following fertilization (Brady & Weil 2016). Electrical conductivity slightly declined (1.36→1.25 mS cm^{-1}), suggesting that fertilizer application did not lead to harmful salt accumulation and that nutrient uptake remained balanced (FAO, 2018). Soil fertility indicators improved, with increases in organic matter (2.93→3.73%) and total nitrogen (0.27→0.52%), reflecting enhanced nutrient retention and biological activity associated with organic amendments (Lal, 2015). Total and available phosphorus and available potassium also increased, indicating improved nutrient availability after fertilization. Calcium and magnesium contents rose as well, suggesting improved soil base status and nutrient balance (Havlin *et al*., 2014).

Overall, the results indicate that the fertilization program not only supported crop production but also improved soil fertility status, contributing to the sustainability of lemongrass cultivation.

Table 4: Soil physicochemical properties before and after the experiment.

Sr. No.	Soil parameter	Unit	Before experiment	After experiment
1.	pH (H_2O)	–	5.81	6.11
2.	pH (KCl)	–	5.36	4.44
3.	Electrical conductivity (EC)	mS cm^{-1}	1.36	1.25
4.	Total organic matter	% (dry soil)	2.93	3.73
5.	Total nitrogen	% (dry soil)	0.27	0.52
6.	Total phosphorus (P_2O_5)	% (dry soil)	0.20	0.26
7.	Available phosphorus (P_2O_5)	% (dry soil)	0.022	0.026
8.	Total potassium (K_2O)	% (dry soil)	0.31	0.32
9.	Available potassium (K_2O)	% (dry soil)	0.14	0.19
10.	Calcium	mg kg^{-1} (dry soil)	568.6	831.9
11.	Magnesium	mg kg^{-1} (dry soil)	6656	6901

CONCLUSION

Inorganic fertilizer regimes significantly influenced the growth, yield components, yield, and economic performance of lemongrass cultivated in Tan Phu Dong. Fertilizer effects became more evident from about 100 days after transplanting onward, particularly for plant height and tiller number.

Among the tested treatments, the 138–48–60 (N–P_2O_5–K_2O) fertilizer regime produced the best overall performance, achieving the highest harvested total biomass yield (58.50 t ha^{-1}). Balanced inorganic fertilization promoted stable vegetative growth, improved productivity, and enhanced economic efficiency, while potentially increasing crop resilience to local climate variability.

FUTURE SCOPE

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