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SHORT COMMUNICATION

Evaluation of an NPK 25:7.5:15 fertilizer blend for enhancing tea (*Camellia sinensis*) yield and nutrient dynamics in Tanzania highlands

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ABSTRACT

Tea (*Camellia sinensis*) production is closely tied to balanced soil nutrient management, particularly nitrogen (N), phosphorus (P), and potassium (K). This study evaluated the impact of a blended NPK 25:7.5:15 fertilizer on green leaf yield and nutrient dynamics across three Tanzania highland regions Mufindi (Iringa), Lupembe (Njombe), and Rungwe (Mbeya) between 2020 and 2024. Using a randomized complete block design, six fertilizer treatments were tested across five nitrogen rates (0–300 kg N/ha), with NPK 25:5:5 as the reference. Results showed that the blended fertilizer significantly improved soil K^+ and enhanced P and K uptake in leaves, especially at 60–240 kg N/ha. Higher nitrogen rates offered no additional benefit, indicating diminishing returns. However, increased electrical conductivity and reduced soil pH highlighted potential soil acidification risks. Regional variation in K uptake emphasized the role of local conditions in nutrient response. The findings suggested that balanced fertilization and site-specific strategies to enhance yield.

Keywords: *Camellia sinensis;* NPK fertilizer; phosphorus; potassium; nutrient uptake; soil fertility; Tanzania highlands; Tea yield

INTRODUCTION

The tea plant (*Camellia sinensis)* is a highly valuable economic crop due to its significant importance in producing tea drink, the world's most popular non-alcoholic beverage (Natumanya Marriet and Mukadasi Buyinza, 2022.) The tea plant leaves are primarily used to produce tea, which contains various characteristic compounds including tea polyphenols, theanine, and caffeine. These compounds not only contribute to the overall quality of tea but also provide numerous health benefits (Xia et al., 2020). Tea plants thrive in soils with good drainage and an ideal pH range of 4.5-5.6. They require a well-distributed rainfall of at least 1200 mm per year, and the optimal mean air temperature for tea cultivation is around 18-25 °C (Alom et al., 2020).

Tea cultivation requires careful attention to nutrient requirements, with nitrogen, phosphorus, and potassium being the major nutrients needed for optimal growth (Hoang et al.,2021). Tea plants have a high nutrient demand due to the frequent harvesting of young leaves, which leads to the continuous depletion of essential soil nutrients. Among these, nitrogen (N) is the most crucial, followed by potassium (K), calcium (Ca), phosphorus (P), sulfur (S), magnesium (Mg), and zinc (Zn). As tea is a leaf crop, nitrogen content is particularly important and tends to be the highest among the three major nutrients, followed by P and Ca and P (Owuorl, 2001). Nitrogen plays a crucial role in the physiology of the plant and is an essential component of various plant parts. It is estimated that the harvestable crop contains approximately 3.5% to 5% nitrogen on a dry matter basis (Lian et al., 2012). Alongside nitrogen, phosphorus (P) and potassium (K) are essential macronutrients that significantly influence both the growth and quality of tea leaves. Deficiencies in these nutrients have been associated with reduced tea yields and compromised leaf quality, often manifesting as lower biomass production and suboptimal leaf morphology. Research indicates that insufficient levels of N, P, and K lead to decreased chlorophyll content, reduced photosynthetic efficiency, and weakened tolerance to environmental stressors, all of which collectively contribute to a decline in tea productivity (Wei et al., 2022).

In East Africa, the recommended economic rate Based on N for tea purposes is generally considered to be 150 kg N/ha. However, higher rates ranging from 200-250 kg N/ha are often used for high-yielding tea estates (Owour, 1997). In Tanzania, it has been observed that up to 300 kg N /ha of nitrogen is applied, particularly in the case of irrigated tea cultivation (TRIT-2019). However, in regions where tea is cultivated experience challenge of p-fixation due to low pH., which lead to low P absorption to plants and caused the low yield and quality due to P deficiency (Heuer et al., 2017). In the other hand, adequate potassium (K) availability plays a vital role in enhancing both the yield and quality of tea, primarily by stimulating metabolic processes, promoting catechin biosynthesis, and strengthening the plant's resistance to biotic and abiotic stresses through the regulation of key enzymatic activities (Huang et al., 2022a). However, potassium uptake can be significantly hindered in acidic soils, where elevated concentrations of competing cations such as hydrogen (H^+), aluminum (Al^{3+}), and iron (Fe^{2+}/Fe^{3+}) interfere with potassium absorption. These cations may either compete directly for root uptake sites or alter the soil chemistry in ways that limit potassium availability and efficiency. In East Africa, tea cultivation has long depended on synthetic compound fertilizers as the main source of essential nutrients. Widely used formulations include NPK 25:5:5:3S and NPK 20:10:10, which are typically applied at nitrogen rates ranging from 150 to 250 kg per hectare annually to satisfy the high nutrient requirements of tea plants (Kwach et al., 2014; Zhu et al., 2024). This study was conducted to evaluate the influence of blended NPK fertilizers with increased phosphorus (P) and potassium (K) concentrations on green leaf yield and nutrient dynamics of tea across different locations within the Tanzanian highlands. In these areas, the commonly used fertilizer formulation is NPK 25:5:5.

MATERIALS AND METHODS

Field trials were conducted in three major tea-producing regions of the Tanzanian highlands Mufindi (Iringa Region), Lupembe (Njombe Region), and Rungwe (Mbeya Region) chosen for their notable contribution to national tea output and their slightly differing agro-climatic conditions, especially in altitude and rainfall. The Mufindi site lies at latitude 8°08′ S and longitude 35°10′ E at an altitude of 1,840 m a.s.l.; Lupembe at 9°26′ S and 34°45′ E at 1,860 m a.s.l.; and Rungwe at 9°32′ S and 33°34.6′ E at 1,315 m a.s.l. A Randomized Complete Block Design (RCBD) with three replications was used for the experimental layout. Two NPK fertilizer formulations were assessed: the standard 5:1:1 ratio (NPK 25:5:5) as a control, and a blended 5:1.5:3 ratio (NPK 25:7.5:15) with higher phosphorus and potassium content. Each fertilizer type was applied at five nitrogen rates: 60, 120, 180, 240, and 300 kg N/ha alongside a control treatment (0 kg N/ha). Fertilizer was applied using a top-dress broadcasting method, commonly recommended for mature tea plantations. Tea harvesting was done manually, targeting two-leaves-and-a-bud shoots.

Soil samples were collected from each plot at a 0–30 cm depth using a soil auger, before and after fertilizer application, in an 'S'-shaped pattern. Composite samples were air-dried, ground, sieved (2 mm), and analyzed for physical and chemical properties. Particle size distribution was assessed via the Bouyoucos hydrometer method; pH was measured in a 1:2.5 soil-to-water ratio. Cation exchange capacity (CEC) was determined using ammonium acetate extraction and potassium chloride displacement, followed by quantification of ammonium ions using the Kjeldahl method. Organic carbon was measured using Walkley and Black (1934) method; total nitrogen by Kjeldahl digestion; and available phosphorus via the Bray-I method. Exchangeable Ca^{2+}, Mg^{2+}, and K^{+} were determined using atomic absorption spectrophotometry and flame photometry. Leaf yield was assessed by weighing harvested green leaf from each plot, and nutrient analysis was done on the third recently matured leaf collected from 100 tea bushes per plot. These leaves were dried, ground, and digested using sulphuric acid, selenium, salicylic acid, and hydrogen peroxide. Post-digestion, N, P, and K concentrations were determined following Okalebo et al. (1993). All soil and leaf data were analyzed using ANOVA in GenStat Discovery Edition 4, with treatment means separated via Tukey's HSD test ($p < 0.05$), and correlation and regression analyses used to explore nutrient uptake relationships.

RESULTS AND DISCUSSION

Influence of P and K on Tea yield (made tea)

The yield of made tea increased proportionally with higher fertilizer application rates across all treatment types (Figure 1). This trend was evident up to nitrogen application rates of 240 kg N/ha. However, yield gains plateaued between 240 kg and 300 kg N, regardless of P and K concentrations. This finding suggests that while phosphorus and potassium enhance tea yield at low to moderate nitrogen rates (60–200 kg N/ha), nitrogen becomes the dominant driver of yield beyond this threshold. In other words, the yield response curve flattens once nitrogen reaches levels that saturate plant demand, thereby masking the incremental benefits of additional P and K inputs. These results align with those reported by Wei et al. (2022), who found that tea yield response to P and K application levels ceases beyond 50 kg P and 170 kg K per hectare, respectively.

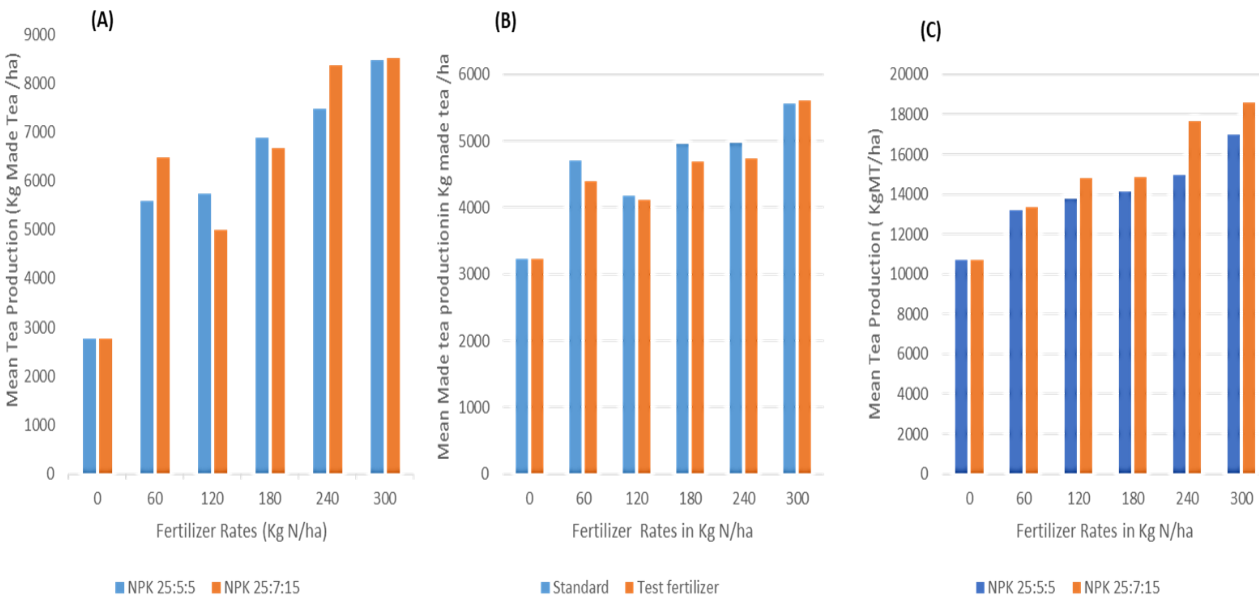

Figure 1. The response of tea yield to elevated phosphorus and potassium levels was assessed across all regions, relative to the yield obtained using the standard fertilizer formulation. A) Tea yield at Mufindi -Iringa, B) Tea yield at Lupembe -Njombe, C) Effects of Fertilizer Rates on Tea Production at Rungwe

Soil nutrient dynamics

Analysis of variance indicated a highly significant effect of fertilizer treatments on soil phosphorus ($F = 55.68$, $p < 0.000001$) and potassium ($F = 5.15$, $p = 0.0009$), confirming that the application of nutrient-enriched fertilizers substantially altered soil nutrient profiles. As shown in Table 1, soil electrical conductivity (EC), nitrogen (%), and K^{+} levels increased following fertilization. Meanwhile, pH declined significantly, and a paradoxical reduction in mean soil phosphorus was observed.

Table 1. Changes in soil chemical parameters before and after fertilization

Parameter	Mean Before	Mean After	Change
pH	5.12	4.56	-0.75
EC	0.11	0.20	+0.27
N (%)	0.34	0.40	+0.06
P	11.73	8.11	-3.62
K^+	0.54	0.63	+0.09

The observed decline in phosphorus (Table 1) content despite higher application rates suggests efficient plant uptake and/or possible leaching losses, particularly under acidic conditions. In contrast, increased potassium concentration indicates better soil retention and availability of K^+, especially in sites with higher cation exchange capacity. Post-treatment nutrient analysis further revealed distinct differences between fertilizer types (Table 2). The A300 treatment applying 300 kg N/ha of an alternative NPK 25:7.5:15 blend resulted in the highest concentrations of both P (14.72 mg/kg) and K^+ (1.24 me/100g). Compared to the control, A300 increased soil potassium by approximately 188% and phosphorus by 99%, demonstrating the superior enrichment capacity of the alternative fertilizer.

Table 2. Soil P and K^+ levels under different fertilizer treatments.

Treatment	P (mg/kg)	K^+ (me/100g)
A300	14.72	1.24
A60	9.25	0.93
A240	10.74	0.83
S300	10.88	0.67
S60	8.11	0.63
Control	7.39	0.43

Note: A= Alternative fertilizer (NPK 25:7.5:15), S= standard fertilizer (NPK 25:5:5)

The enhanced performance of the alternative NPK 25:7.5:15 fertilizer is consistent with findings by Tang et al. (2023), who noted that formulations with higher P and K content significantly improve nutrient bioavailability in acidic soils. Similarly, Kamiri et al. (2018) emphasized the importance of balanced fertilization in improving nutrient absorption, particularly in low-fertility soils. Despite the nutritional benefits, results also highlighted emerging soil health concerns. The marked drop in pH and rise in EC following high-input fertilization reflects the acidifying effect of repeated synthetic fertilizer application an effect documented in other long-term studies (Ng'etich et al., 2010). Increased acidity can impair root development, hinder microbial activity, and reduce nutrient solubility, posing risks to long-term soil productivity. Mitigating these effects may require periodic liming or integration of organic and organo-mineral fertilizers to buffer pH decline and improve microbial resilience (Syed et al., 2021; Srinivasarao et al., 2024). Although phosphorus levels declined post-treatment, the corresponding increase in leaf P concentration suggests efficient uptake. Similar dynamics were observed for potassium, particularly in Njombe and Rungwe, where higher rainfall and favorable soil textures likely enhanced root absorption and K^+ mobility. These site-specific differences underscore the need for tailored fertilization strategies based on agroecological conditions, rainfall distribution, and inherent soil nutrient status (Huang et al., 2022b).

CONCLUSION

This study demonstrated that applying a blended NPK 25:7:15 fertilizer with elevated phosphorus and potassium significantly improved soil nutrient availability and tea leaf nutrient content across the Tanzania highlands. Yield responses were most pronounced at low to moderate nitrogen rates (60–240 kg N/ha), indicating a synergistic effect among nutrients. Beyond this range, nitrogen became the primary driver of yield gains, suggesting diminishing returns from additional P and K. The results underscore the importance of balanced fertilization in optimizing nutrient uptake and enhancing tea productivity, especially in nutrientdeficient soils. However, intensive fertilizer use was associated with soil acidification and increased electrical conductivity, highlighting potential long-term risks to soil health. To ensure sustainable production, integrated soil fertility management, including the use of organo-mineral and organic amendments is recommended. The observed regional differences in nutrient uptake point to the need for site-specific fertilizer strategies that consider local agroecological factors. Tailoring nutrient applications to these conditions is important for maximizing efficiency, sustaining yields, and preserving soil quality over time.

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AUTHORS CONTRIBUTIONS

Braison Mjanja: conceptualization, investigation, data analysis and extraction and synthesis, writing- original draft, writing review and editing, and validation. Rhoda Chacha: conceptualization, formal analysis, writing review and editing: Magreth Katole: Supervision, investigation, and editing. Lameck Maleba: Field data collection, writing review and validation. Vilumba Kyando: Investigation, writing review and editing. Amos Makweta: Research proposal, experiment design, conceptualization and editing.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

ETHICAL APPROVAL

Not applicable

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AVAILABILITY OF DATA AND MATERIALS

All datasets analyzed and described during the present study are available from the corresponding author upon reasonable request.

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