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Effect of different concentration of mineral fertilizers on growth and yield of *Curcuma longa* L. in Surkhandarya region, Uzbekistan

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Abstract

The application of mineral fertilizers plays a crucial role in improving the growth parameters and yield potential of turmeric. This study was carried out in the Surkhandarya region of Uzbekistan to evaluate the influence of different fertilizer treatments on turmeric cultivation. A field experiment was designed with four treatments: T1 (Control), T2 (N75P50K50 kg/ha), T3 (N125P100K100 kg/ha), and T4 (N100P75K75 + B3Zn6Fe6 kg/ha), the latter referred to as the macro- and micro-nutrient fertilizer (MMNF). Both the T3 and MMNF treatments led to notable improvements in leaf length, number of leaves, leaf width, and plant height compared to the control at 120 and 180 days after planting. MMNF treatment exhibited the highest values for all growth parameters under the region's climatic conditions. Fresh rhizome yield per plant also significantly increased under T3 and MMNF treatments. Specifically, T3 improved yield by 119.7%, while MMNF resulted in a 132.4% increase over the control. Moreover, a very strong positive correlation was observed between leaf width and both rhizome yield per plant and per square meter. Similarly, leaf length showed a highly significant positive correlation with rhizome yield metrics. These findings suggest that MMNF is the most effective among the tested treatments for enhancing turmeric yield under field conditions. Notably, this is the first documented field study on turmeric cultivation using rhizomes in Uzbekistan.

1. Introduction

Medicinal plants are essential components of global healthcare systems due to their abundance of bioactive phytochemicals with established therapeutic properties (Balciunaite *et al*., 2020; Nwozo *et al*., 2023; Abdallah *et al*., 2023). According to the World Health Organization, approximately 80% of the global population depends on traditional herbal remedies, driving an increasing interest in natural and organic health products (Maroyi, 2013). Unlike staple food crops, the economic and medicinal value of plants like turmeric (*Curcuma longa* L.) lies in the accumulation of secondary metabolites, which are strongly influenced by soil nutrient availability (Kumar *et al*., 2022). Therefore, effective nutrient management is critical to enhancing both the yield and therapeutic quality of these compounds (Singh *et al*., 2017).

Turmeric, a prominent species in traditional Asian medicine, serves as a model for understanding how soil fertility shapes the production of medicinally valuable compounds. Known in Ayurveda as "Amraharidra," turmeric is highly regarded for its curative propertiesincluding anti-inflammatory, digestive, and neuroprotective effectsprimarily ascribed to its active compound, curcumin (Goozee *et al*., 2016; Brijesh and Ajjappala, 2023; Genchi *et al*., 2024). Its multifaceted bioactivity, particularly its antimicrobial and anticancer potentials, has led to rising industrial and pharmaceutical demand (Sharifi-Rad *et al*., 2020; Zheng *et al*., 2021). However, the crop's growth performance and curcumin biosynthesis are highly dependent on soil nutrient levels. Inadequacies in macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), alongside micronutrients including boron (B), zinc (Zn), and iron (Fe), can significantly restrict rhizome growth and metabolite content (Adekiya *et al*., 2019; Zhang *et al*., 2021).

To overcome these challenges, mineral fertilizers offer a reliable method for enhancing soil nutrient status and plant uptake efficiency. Their application not only improves overall crop productivity but also increases the mineral density of harvested turmeric rhizomes (Jabborova *et al*., 2021a). For example, NPK supplementation has been found to elevate nutrient content in ginger rhizomes by up to 40% (Yanthan *et al*., 2010), while integrated use of macro- and micronutrients (such as NPK + BZnFe) has shown promising results in improving turmeric yield and stress tolerance (Srinivasan *et al*., 2016). Despite these insights, there is a lack of localized data from Central Asia, especially in the arid conditions of Uzbekistan. Expanding on earlier work (Jabborova *et al*., 2021b), this research explores the impact of mineral fertilization strategiesincluding a

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specially formulated macro- and micronutrient blend (MMNF) on the growth dynamics and productivity of turmeric cultivated in the Surkhandarya region. By comparing four fertilization treatments, this study aims to: (1) assess the combined effects of micronutrient-enriched NPK formulations, and (2) provide region-specific guidance for improving turmeric cultivation in nutrient-deficient soils. The outcomes are expected to bridge knowledge gaps in sustainable spice agriculture and contribute to global efforts in understanding nutrient–metabolite relationships in medicinal crops.

2. Materials and Methods

2.1 A Field experiments

The *C. longa* was authenticated by OrzimatTurginov (National Herbarium of Uzbekistan (TASH) and DilfuzaJabborova (Institute of Genetics and Plant Experimental Biology) Tashkent, Uzbekistan. A Voucher Specimen No. 07052025 was placed in the Herbarium unit. A field experiment was conducted to study the effect of mineral fertilizers on growth (Figure 1) and yield of turmeric.

Figure 1: Growth of turmeric under field conditions.

In 2020-2022 year, the experiment was carried out in Randomized Block Design with five replications at the Surkhandarya Scientific Experimental Station of the Vegetable, Melon Crops and Potato Research Institute, Uzbekistan. Experimental treatments included: Control with no fertilizers (T-1), $N_{75}P_{50}K_{50}$kg/ha (T-2), $N_{125}P_{100}K_{100}$kg/ha (T-3) and $N_{100}P_{75}K_{75}$+ $B_3Zn_6Fe_6$kg/ha (T-4, MMNF). Rhizomes were sown in March (2020-2022 years). Plant growth parameters were measured for three and six months of growth periods. Turmeric rhizomes were harvested after 240 days of cultivation.

2.2 Statistical analysis

ANOVA was used to examine experimental data with the IBM SPSS Statistics 20. Analysis of variance (ANOVA) was conducted to compare the significant or insignificant difference in the effect of treatments on growth and yield of turmeric using Duncan's Multiple Range test with the least significant difference at a 5% level of significance ($\alpha = 0.05$).

3. Results

3.1 Growth of turmeric

Based on the analysis of the experimental results, notable improvements in turmeric plant growth were observed under the application of N125P100K100 kg/ha and the macro- and micronutrient fertilizer (MMNF) compared to the untreated control (Figure 2). Specifically, the treatment with N125P100K100 kg/ha resulted in a 52.4% increase in plant height at 120 days after planting relative to the control. The most substantial enhancement; however, was recorded under the MMNF treatment, which produced the highest plant height values at both 120 and 180 days. At the 120-day mark, the MMNF application led to a 68.9% increase in plant height compared to the control, demonstrating a statistically significant improvement.

An evaluation of leaf number in turmeric plants at 120 days revealed an increase of up to 51.5% following the application of either N125P100K100 kg/ha or the macro- and micronutrient fertilizer (MMNF), in comparison with the untreated control. At 180 days, the NPK treatment (125:100:100 kg/ha) led to a significant rise in leaf number, showing a 63.6% improvement over the control. Among all treatments, the MMNF application produced the highest number of leaves, indicating its superior effectiveness in enhancing foliage development (Figure 3).

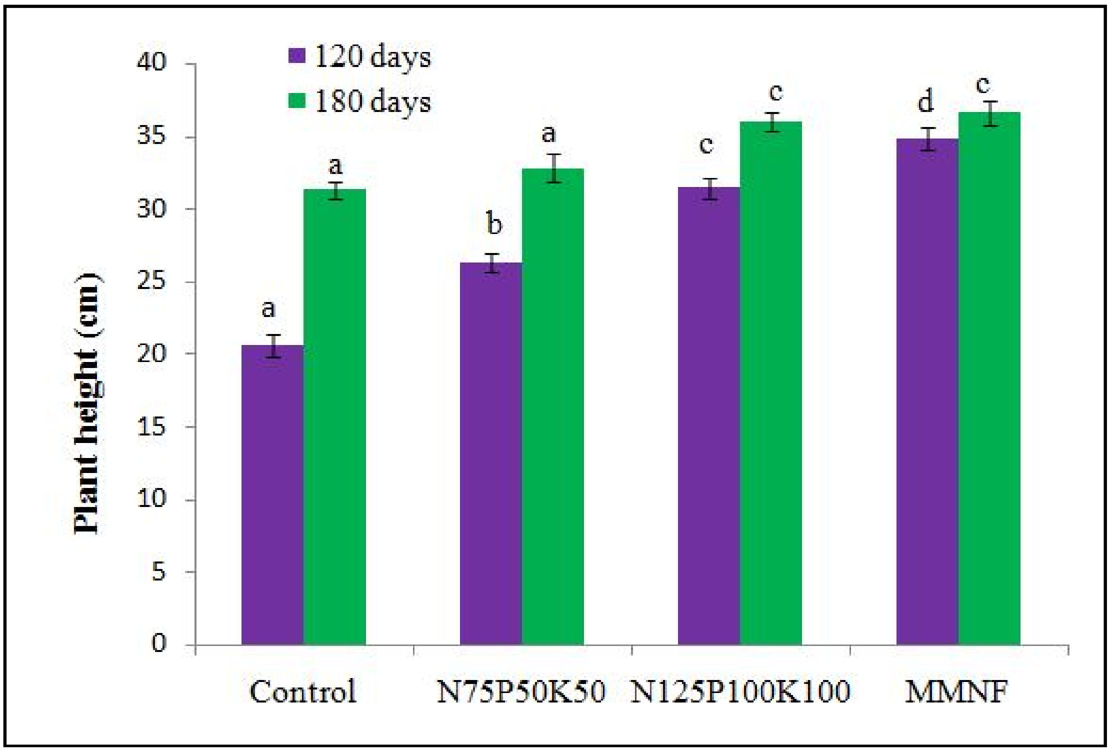

Figure 2: Effect of mineral fertilizers on plant height of turmeric.

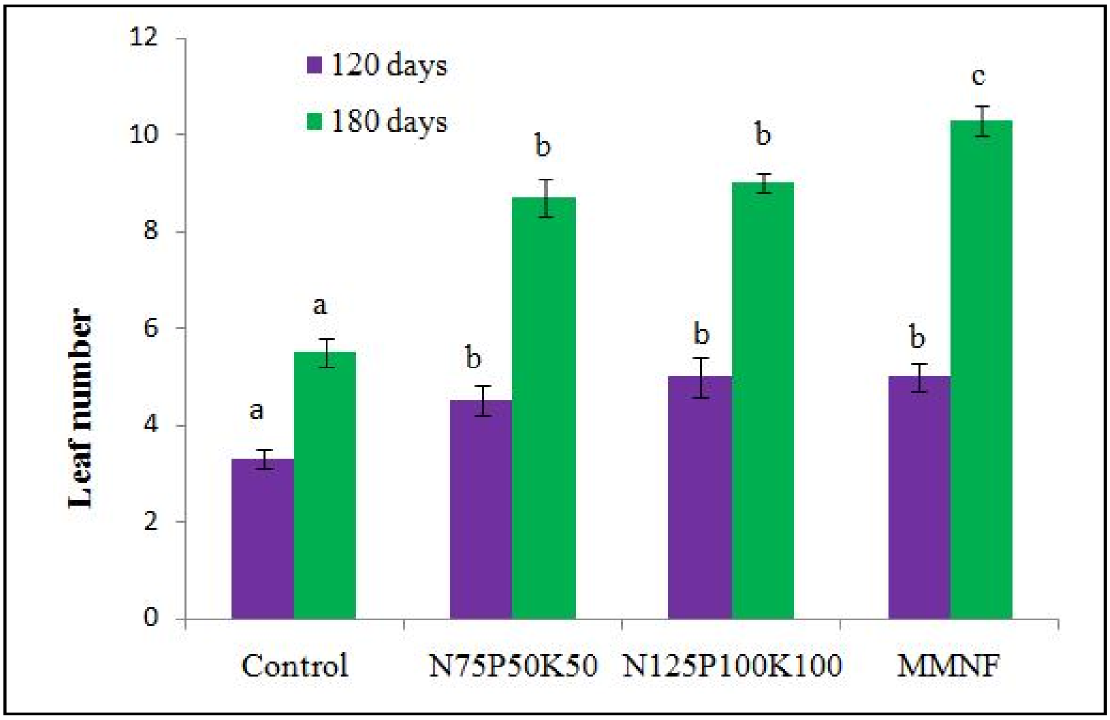

Figure 3: Effect of mineral fertilizers on leaf number of turmeric.

The analysis of turmeric plant leaf length over a period of 120 days revealed a 36.6% increase when treated with N125P100K100 kg of fertilizer per hectare and a 40% increase with the application of a macro- and micronutrient fertilizer (MMNF). After 180 days, the treatment with N125P100K100 kg of fertilizer per hectare showed a 21.6% improvement in leaf length compared to the control group (Figure 4). Across both 120 and 180 days, the highest leaf length growth was observed in plants treated with MMNF under the climatic conditions of the Surkhandarya region.

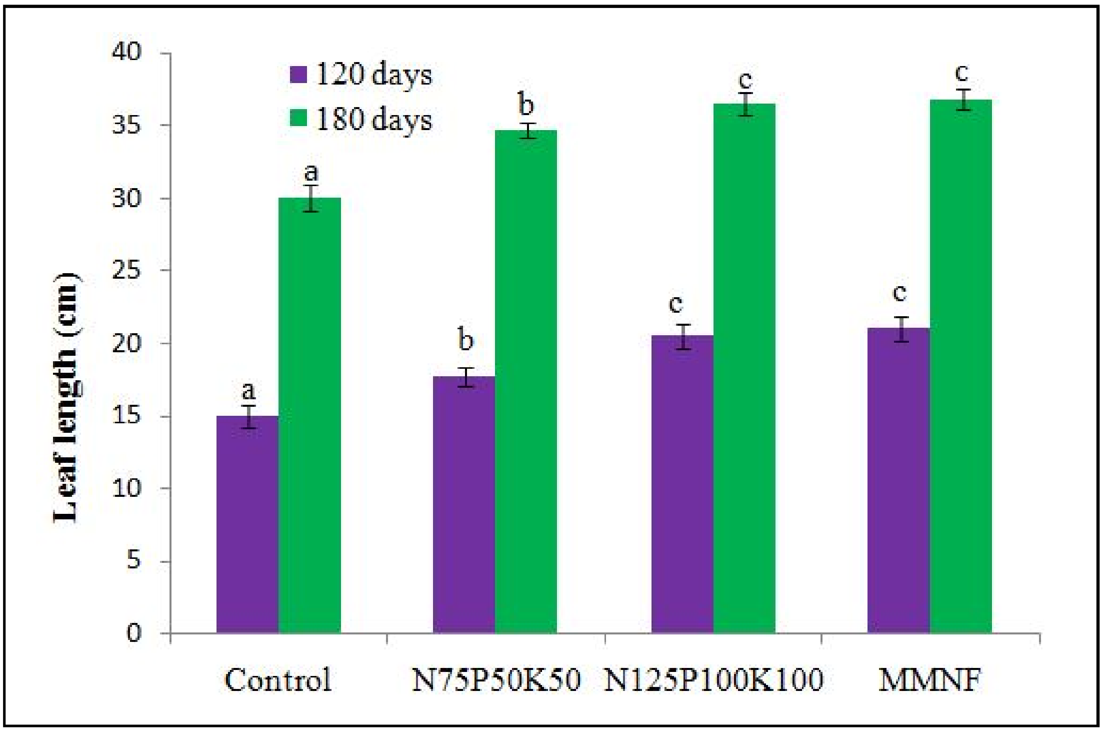

Figure 4: Effect of mineral fertilizers on leaf length of turmeric.

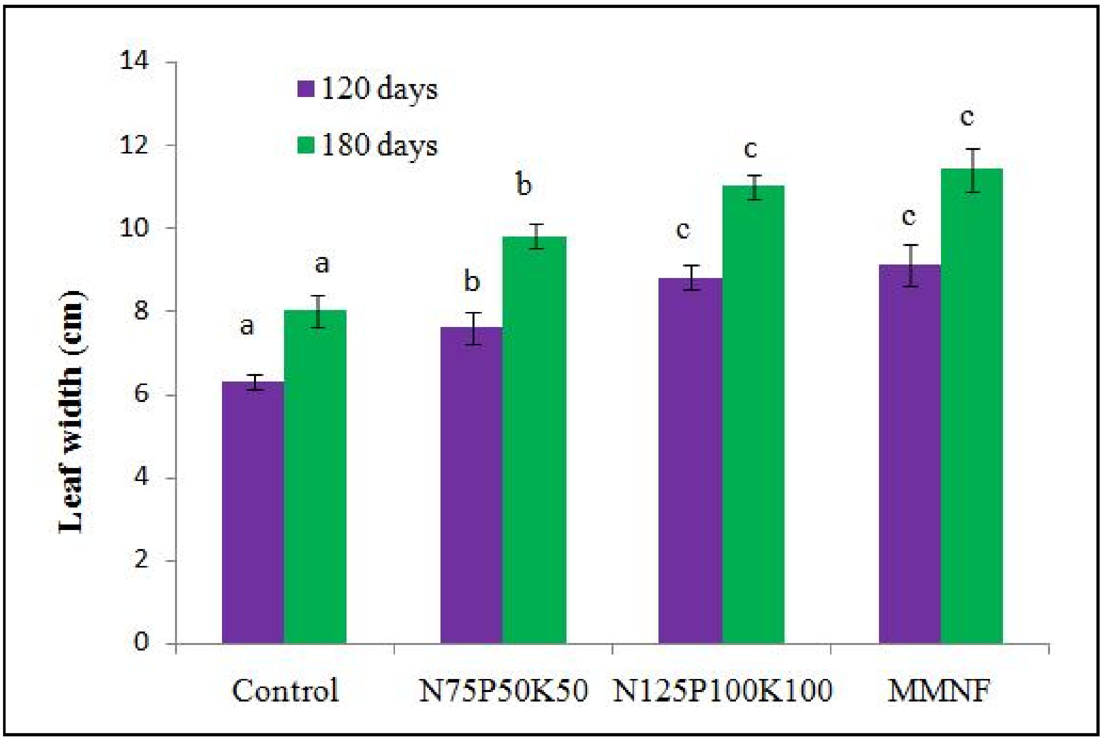

Figure 5: Effect of mineral fertilizers on leaf width of turmeric.

The analysis of turmeric plant leaf width over 120 days showed an increase of 39.6% with the application of N125P100K100 kg of fertilizer per hectare, and a 44.4% increase with the use of macro- and micronutrient fertilizer (MMNF), compared to the control group (Figure 5). After 180 days, the application of NPK (125:100:100 kg/ha) and MMNF treatments resulted in a significant enhancement in leaf width, with increases of 37.5% and 42.5%, respectively, compared to the control treatment with no fertilizer.

3.2 Yield of turmeric

The data presented in Figure 6 indicated that mineral fertilizers enhanced the fresh rhizome yield of turmeric per plant. The highest fresh rhizome yield was observed with the NPK application rate of 125:100:100 kg/ha and MMNF treatments, compared to the control. The application of N125P100K100 kg of fertilizer per hectare resulted in a significant increase of 119.7% in the rhizome yield per plant compared to the control. Additionally, MMNF treatments led to a notable increase of 132.4% in rhizome yield per plant over the control.

When analyzing the turmeric yield (1m²/g) based on different treatments, the fresh rhizome yield was notably higher with the application of N125P100K100 kg per hectare and MMNF. Among these, the MMNF treatment yielded the highest results. Specifically, MMNF treatments led to a significant increase of 132.4% in rhizome yield per square meter compared to the control (Figure 7).

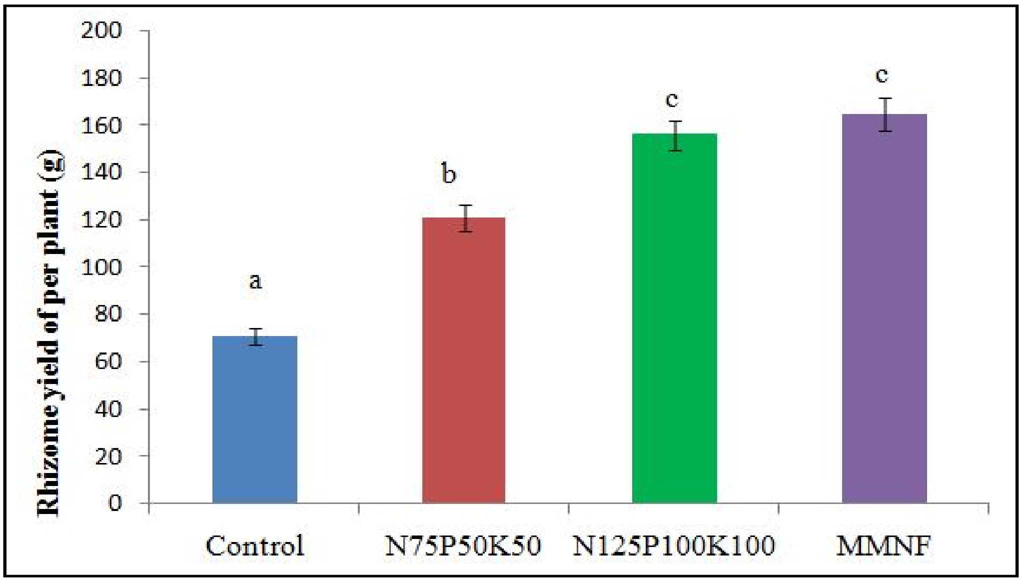

Figure 6: Effect of mineral fertilizers on rhizome yield of per plant.

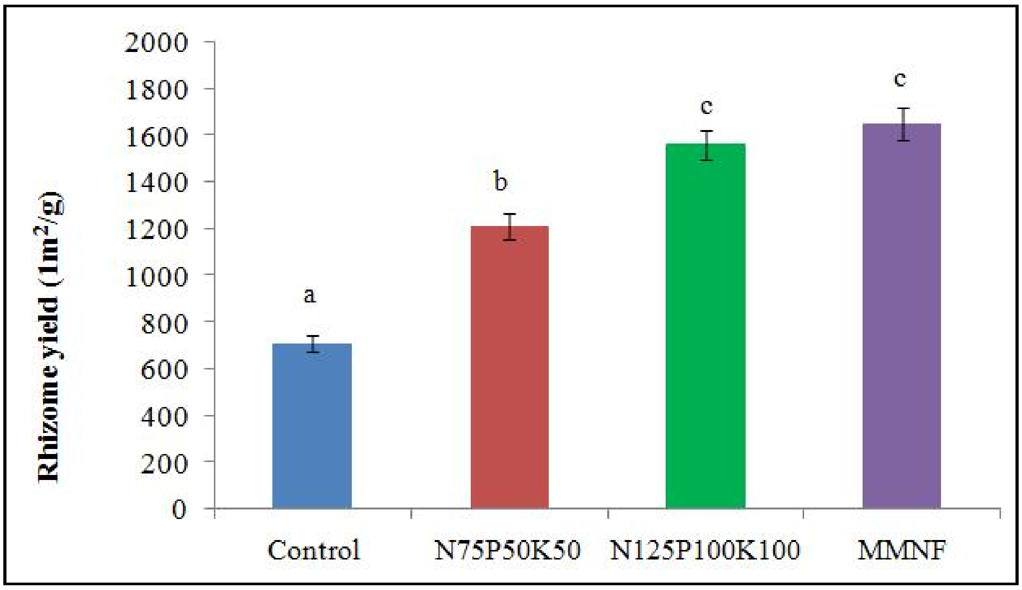

Figure 7: Effect of mineral fertilizers on rhizome yield (1m²/g).

3.3 Heat map analysis of various treatments

The effects of mineral fertilizers on the growth parameters and yield of turmeric were assessed using a heat map clustering (Figure 8). The heat map, generated based on Pearson and Ward methods for determining distance and clustering, illustrates the impact of different mineral fertilizers on turmeric growth and yield. The dendrogram analysis revealed that the treatments were divided into two main categories: the control group and treatment 2 (N75P50K50 kg/ha), which showed a negative effect on turmeric growth. In contrast, treatment 3 (N125P100K100 kg/ha) demonstrated a positive effect on plant growth and yield. Treatment 4 (MMNF) showed the most favorable influence on both growth parameters and rhizome yield of turmeric.

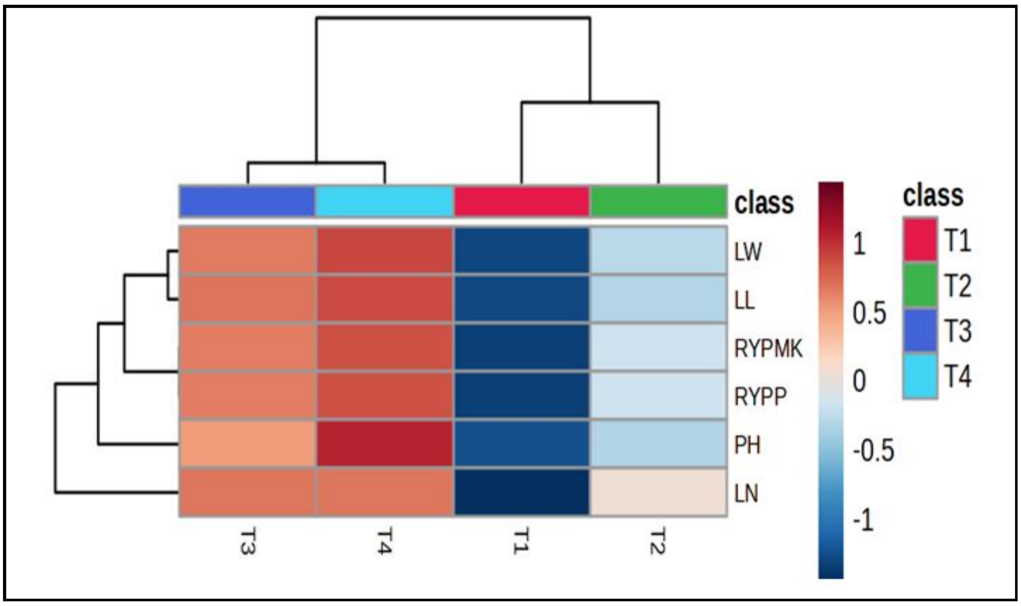

Figure 8: **The heat map based on Pearson and Ward for determining distance and clustering shows the effect of mineral fertilizers on growth and yield of turmeric.**

Note: LW-leaf width, LL-leaf length, RYPMK-rhizome yield (1m^2/g), RYPP- rhizome yield per plant, PH-plant height, LN-leaf number.

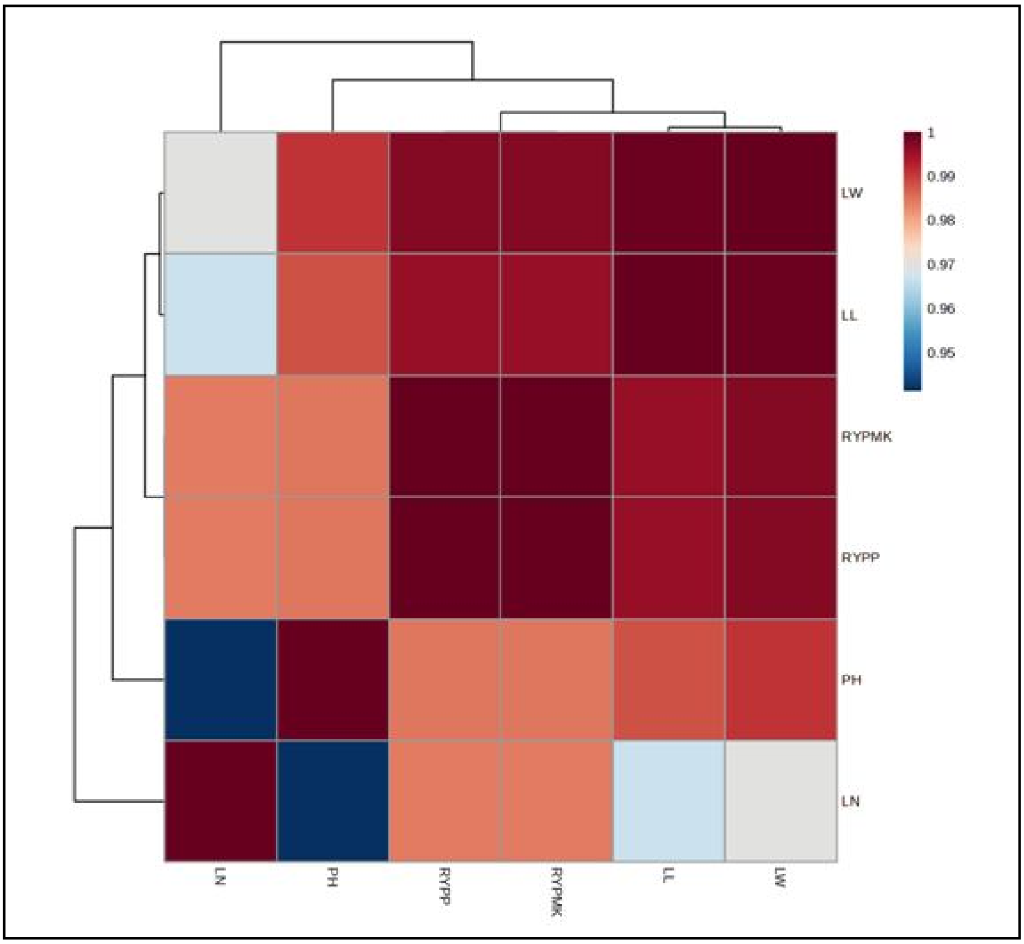

Figure 9: **Correlation heat maps of growth and yield of turmeric (Pearson r).**

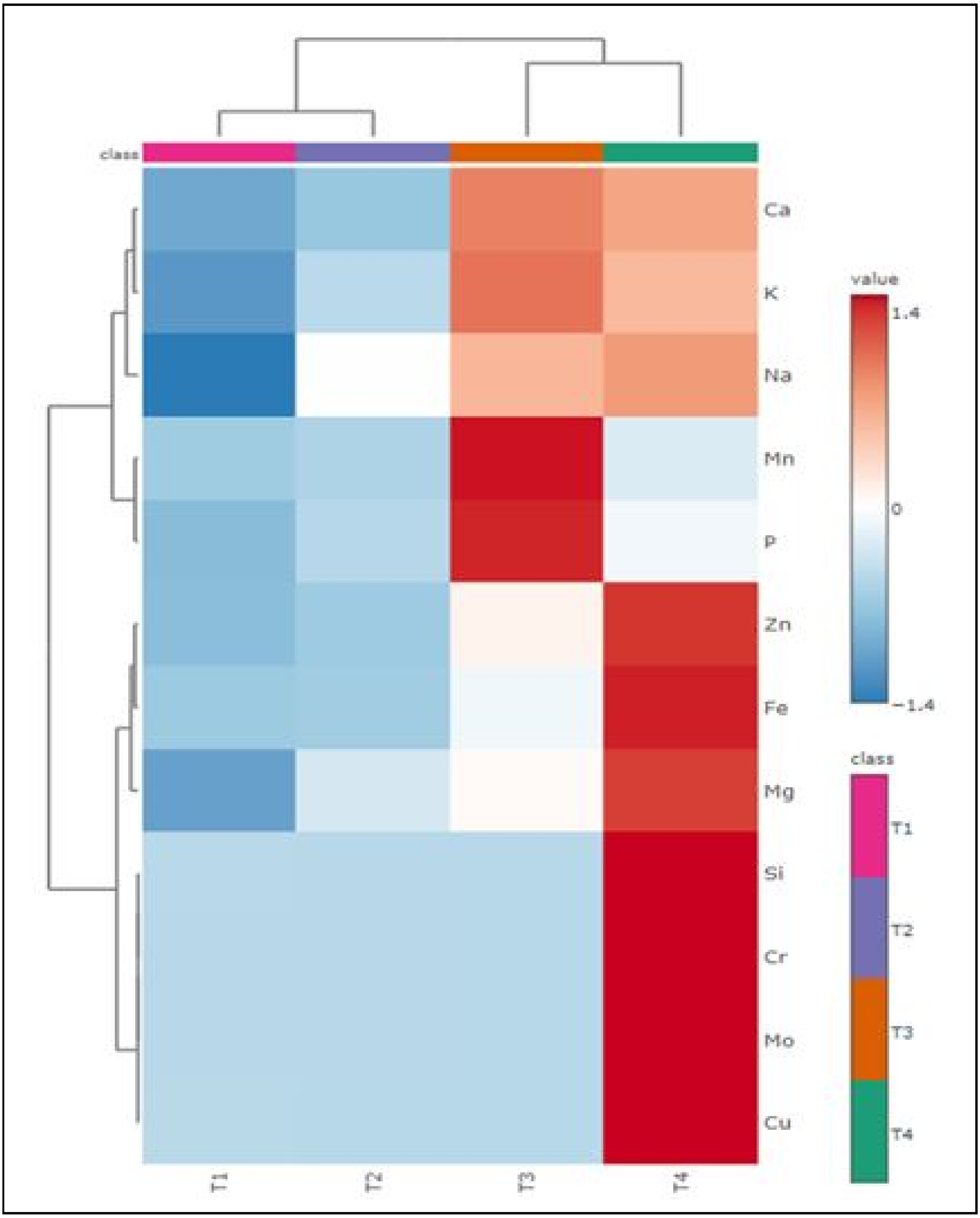

Figure 10: The heat map based on Pearson and Ward for determining distance and clustering shows the effect of mineral fertilizers on macro-microelements of rhizome in turmeric.

The interrelationships between the study variables were analyzed using Pearson's correlation test and presented as a heat map in Figure 9. In the heat map, red boxes represent a highly positive correlation between variables, salmon boxes indicate a medium significant positive correlation, and blue boxes denote a low significant positive correlation. The analysis revealed that leaf width exhibited an extremely significant positive correlation with leaf length, rhizome yield per plant, and rhizome yield of turmeric ($1m^2/g$). Leaf width also showed a medium significant positive correlation with plant height. Leaf length values were highly positively correlated with rhizome yield per plant and rhizome yield of turmeric ($1m^2/g$), while also demonstrating a medium significant positive correlation with plant height. Plant height values were strongly correlated with leaf length, and medium significant positive correlations were observed between plant height and rhizome yield per plant and rhizome yield of turmeric ($1m^2/g$). Additionally, leaf number showed a medium significant positive correlation with both rhizome yield per plant and rhizome yield of turmeric ($1m^2/g$).

The impact of mineral fertilizers on the content of macro- and microelements in the rhizomes of turmeric, grown under the soil-climatic conditions of the Surkhandarya region, was analyzed using a clustering method (heat map). Figure 10 clearly shows the differences between the control group (without fertilizer treatment) and the treatments with mineral fertilizer applications. The dendrogram indicates that the treatments either had a positive or negative effect on the macro- and microelement content in the rhizomes of turmeric. Specifically, the control (T1) and treatment T2 showed a negative effect on the macro- and microelement content. In contrast, treatment T3, with the application of N125P100K100 kg per hectare, had a positive effect on the content of macroelements (K, Ca, Na, P) and microelements (Zn, Mn) in the rhizomes. Treatment T4 also demonstrated a positive effect, influencing the content of macroelements (K, Ca, Na, Mg) and microelements (Si, Mo, Zn, Fe, Cr) in the rhizomes. While all treatments were significantly different from each other, they exhibited varying effects on the macro- and microelement content in the rhizomes of turmeric plants grown in the Surkhandarya region.

4. Discussion

Soil fertility can be quickly depleted when cultivating crops like turmeric, which has high productivity and an extended growth period of approximately eight months (Adekiya *et al*., 2019; Sharangi *et al*., 2025). As a result, turmeric requires significant fertilizer inputs to ensure optimal growth. The combined application of NPK and micronutrients has been shown to improve both physicochemical soil properties and enzyme activities, which are crucial for plant development (Jabborova *et al*., 2021b). Although, numerous studies have examined the effects of various fertilizers on turmeric growth and yield in other countries (Datta *et al*., 2017a; Adekiya *et al*., 2019; Bairagi, 2022), there is no official publication addressing the effects of mineral fertilizers on turmeric cultivation in the Surkhandarya region of Uzbekistan.

In this study, notable improvements in turmeric growth parameters, such as plant height, number of leaves, leaf length, and leaf width, were observed following the application of NPK fertilizer at a rate of 125:100:100 kg/ha and macro- and micronutrient fertilizer (MMNF) at both 120 and 180 days after planting. The fresh rhizome yield per plant also showed the highest increase with the NPK application (125:100:100 kg/ha) and MMNF treatments, with improvements of 119.7% and 132.4%, respectively, compared to the control. These results align with previous research by El-Hawaz *et al.* (2016), which demonstrated that specific mineral fertilizer combinationssuch as 3.54 mM PO^3, 5.7-6 mM Ca^2z , and 60 mM KNO_2 enhanced turmeric rhizome production by 50.7 ± 2.8 g dry mass per stock plant under greenhouse conditions. Additionally, an *in vitro* study by El-Hawaz *et al*. (2015) further supported the positive impact of mineral nutrition on turmeric growth and development.

The application of various micronutrients to turmeric has been shown to increase both yield and associated growth parameters. Several studies, including those by Halder *et al*. (2007); Vishwanath *et al*. (2011); Kamble *et al*. (2014); Singh (2014), Datta *et al*. (2017a); Hnamte*et al*. (2018); Chitdeshwari (2019); Prasath et al. (2024) reported the significant influence of micronutrient mixtures on turmeric yields. These studies demonstrated a range of 21.0 to 35.3 tons per hectare for fresh rhizomes and 3.88 to 6.60 tons per hectare for dry rhizomes in different soil types, including red sandy loam and black sandy clay soils.

In addition, Datta *et al*. (2017b) examined the effects of micronutrients like boron (B), iron (Fe), manganese (Mn), and zinc (Zn) on turmeric growth and yield. Their study found that soil application of boron, in the form of borax at 25 kg/ha, resulted in the highest yield11.13 kg per 3 m² or 22.45 t/ha significantly out performing the control treatment. Furthermore, the highest secondary rhizome weights were recorded with soil applications of manganese ($MnSO_2$) at 25 kg/ha (81.95 g), iron (Fe, SO_2) at 25 kg/ha (81.85 g), and boron (borax) at 25 kg/ha (80.76 g). These findings indicate that the application of specific micronutrients, particularly boron, manganese, and iron, can significantly enhance turmeric growth and yield. These improvements are likely due to the roles these micronutrients play in enhancing photosynthetic activity, protein synthesis, and reproductive development (Hnamte*et al*., 2018).

5. Conclusion

Turmeric plants were cultivated in soil treated with various doses of macronutrients (chemical fertilizer) either alone or in combination with micronutrients, referred to as macro- and micronutrient fertilizer (MMNF). The growth parameters, including leaf number, leaf length, leaf width, plant height, and fresh rhizome yield, were significantly higher in the MMNF-treated soil compared to treatments with chemical fertilizer alone and the control. The yield of turmeric showed significant improvement with the application of the macro- and micronutrient fertilizer (MMNF) at the optimal rate of N100P75K75 + B3Zn6Fe6 kg/ha. The MMNF treatment exhibited a positive correlation with most of the growth parameters and yield metrics, particularly in plant height, leaf number, leaf length, leaf width, and fresh rhizome yield of turmeric. These findings underscore the effectiveness of combining macronutrients and micronutrients in boosting turmeric's growth and productivity. Therefore, the results support the recommendation of using a combined macro- and micronutrient regimen for optimal turmeric cultivation in the Surkhandarya region of Uzbekistan.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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