

Long Term Influence of High Rates of Nitrogenous Fertilizer on Seedling Tea: 1. Effects on Young and Mature Leaf Nutrients Contents

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ABSTRACT

Nitrogen (N) fertilization is a key agronomic input in tea production. However, the impacts of continuous long-term application of high rates of the nutrient on the dynamics of tea leaf nutrients contents remain insufficiently understood. This study evaluated the effects of continuous application for 40 years, of high nitrogen fertilizer rates (up to 800 kg N ha⁻¹ year⁻¹) on mature and young tea leaves nutrients contents of seedling tea in a field trial at Timbilil Estate, Kenya. Both mature and young leaves exhibited significant ($p \leq 0.05$) increases in nitrogen, manganese, aluminium, iron and zinc contents with rising N rates. However, leaf phosphorus, potassium, calcium, magnesium, and barium concentrations declined with increasing rates of nitrogen applications. The changes were more severe than those observed in previous short term low rates of nitrogen fertiliser trials. These results demonstrate that the continuous long term application of high rates of nitrogen could be causing nutrients imbalance in tea plants that may make tea production unsustainable in the long run. The continuous application of high rates of nitrogen should be discouraged in tea production.

Keywords: Tea, High rates of nitrogenous fertilizer, Micronutrients, Macronutrients.

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INTRODUCTION

Demand for tea (*Camellia sinensis* [L.] O. Kuntze) remains high in the world^{1,2} motivating producers to intensify productivity through agronomic interventions. Among essential agronomic practices, nitrogen fertilizer use plays a pivotal role in promoting growth, yield, and plant health.³⁻⁵ In East Africa, the recommended nitrogen application rates range from 100 to 250 kg N ha⁻¹ year⁻¹, depending on yield potential of the tea genotype.⁶ However, rates outside this range, either too low or excessively high, have been associated with yield reductions.^{7,8} Before 1983, nitrogen application beyond 400 kg N ha⁻¹ year⁻¹ had not been considered in Kenya as it was believed such rates could cause adverse physiological effects in tea, such as plasmolysis. However, countries like Japan, which predominantly produce green tea, routinely apply rates as high as 1200 kg N ha⁻¹ year⁻¹.⁹ Most studies, have reported nutrients contents of mature and young leaves from short term studies usually after less than 20 years of experimentation.^{4,8,10,11} Although these studies provided results that suggested either declining or increasing nutrients levels with increase in nitrogenous fertiliser rates, there has been no effort to evaluate if prolonged continuous use of nitrogen would lead to either very high or very low leaf nutrients content. Application of nitrogenous fertilizers increase soil acidity,^{12,13} which ultimately influences soil nutrients availability.^{13,14} In countries where high rates of nitrogen are applied to tea, interventions by liming^{15,16} or use of organic manures^{13,17} are recommended practices to curb the adverse changes in soil acidity and nutrients availability. Liming is however, not a recommended practice for the East African teas as it restrict tea growth.^{14,18} The influence of the long-term continuous application of high rates of nitrogen fertilizer on leaf nutrients composition remains inadequately explored.

Short-term trials in Kenya revealed that high nitrogen rates altered nutrient uptake in both young and mature leaves, typically increasing nitrogen, manganese, and aluminium while reducing potassium and phosphorus.^{4,14,19} However, the implications of continuous use of high rates of nitrogen over multiple decades on nutrients dynamics in tea leaves remain poorly understood.

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Sustained high rates of nitrogen application may alter soil acidity, deplete essential nutrients, and/or lead to accumulation of some elements to toxic levels in the leaves.^{3,20,21} Such changes may pose risks to long-term soil fertility, tea yield, tea plant health and eventually human health. A long-term study to evaluate the influence of high nitrogen rates on tea production and black tea quality in Kenya was initiated in 1983 on seedling tea using rates of up to 800 kg N ha⁻¹ year⁻¹.²² Despite, the use of high rates of nitrogen, there were no attempts to control soil pH using lime^{15,16} or organic manures.^{13,17} The aim of this study was to evaluate the effects of 40 years of continuous application of high nitrogen fertilizer rates on tea leaf nutrient profiles (mature and young leaves). The findings are expected to inform sustainable nitrogen management practices, ensuring long-term soil health, tea quality, and economic viability for tea producers in Kenya and other tea-growing regions.

Experimental

The research was superimposed on an on-going trial/experiment at Timbilil Estate of the Kenya Agricultural and Livestock Research

Organization, Tea Research Institute (KALRO-TRI) Kericho, Kenya located on latitude 0° 22'S and longitude 35° 21'E with altitude of 2180m above sea level. The trial was 40 years old when leaf sampling was done. This trail was laid on seedling tea planted in 1960 at a spacing of 122 cm by 122 cm. Prior to the planting of the tea, the field was under natural forest. The field continued to be maintained using recommended tea agronomic practices. However, no fertilizer was applied to the field for 10 years prior to the commencement of the trail.^{7,8,23} The experiment was then initiated in March 1983 using completely randomized block design and fertilizer application was started in September 1983.²² The plots received annual fertilizer applications at rates of 0, 50, 100, 200, 400 and 800 kg N ha⁻¹ year⁻¹ as NPKS 25:5:5:5²² until 2006 when it was changed to NPK 26:5:5.

In March 2024 leaf sampling was done as mature leaf²⁴ and young leaf (2 leaves and a bud). About 100g of each type of leaf was sampled. The samples were oven dried at 105°C using Memmert oven (D-91126) for 12 hours then milled to powder (<1 mm) using an electric motor grinder (Moulinex AR1043). The powdered samples were kept in labelled paper envelopes for laboratory mineral nutrients analysis. One gram of powdered plant tissue was dry-ashed in a 15-ml high-form porcelain crucible in a Muffle furnace at 500°C for 4.5 hours. The ash was cooled to room temperature, then digested with 0.5 mL mixture of double acid (Conc. HCl and HNO₃ in 1:1 ratio) and hydrogen peroxide (double acid and hydrogen peroxide in ratio 2:3). The digests were evaporated to complete dryness on a hot plate under low heat and ventilation. The final residues were cooled and then extracted using 25 mL of 0.5N HCl solution. Mature leaf nutrients levels were then determined using ICP-AES 9000. Leaf nitrogen was determined from 0.1g of powdered leaf samples that were micro-Kjedahl digested for 4.5 hours using 1 mL of concentrated sulphuric acid in the presence of a catalyst mixture consisting of selenium, copper sulphate and potassium sulphate in a block digester. The digests were cooled to 25°C and 10 mL of distilled water added, then subjected to rapid steam distillation in a steam distiller (Vapodest 50 series, Germany) using 40% NaOH for ammonia gas to be driven off by steam. Ammonia was condensed and allowed to drip into 2% boric acid mixed with an indicator mixture (methyl red and bromocresol green) as the receiving solution. The resultant mixtures was then titrated with 0.5 N hydrochloric acid solution. The data obtained were subjected to statistical analysis using ANOVA using GenStat statistical package.

RESULTS AND DISCUSSION

Leaf analysis has been used as diagnostic tool in predicting plant nutritional requirements.^{25,26} Young tender leaves have been used to predict nutrients status of tea in some tea producing countries including Taiwan, India, and Russia.^{9,27} However, Eastern African^{24,28} and Central African²⁹ tea use mature leaf analysis as predictors for macronutrients deficiencies in the plant. In Kenya, the use of

mature leaf was adopted by the advisory system to guide nutrients management^{19,24,28,30} and critical nutrients levels for some essential nutrients (Table 1) were set based on this basis.³⁰

Mature leaf nitrogen increased ($p \leq 0.05$) with nitrogen rates (Table 2). Similar increase in mature leaf nutrients had been recorded in previous studies^{10,11,19,31} and previous data from early stages of this experiment.³² The level of leaf nitrogen therefore were not continuously changing as had been anticipated. The recorded level of nitrogen can be attributed to the available soil nitrogen from the applied fertilizer. Application of nitrogenous fertilizer is therefore an appropriate method of availing the nutrient to the plant.

Mature leaf nitrogen levels below 3% (Table 1)²⁴ is considered deficient.³⁰ The continuous non-application of nitrogen resulted in nitrogen deficiency (Table 2). In some previous experiments use of nitrogen rates below 150 kg N showed mild deficiency status in both clonal tea^{4,11,14,19,31} and seedling tea,¹⁰ although the response varied with region of fertilizer application.^{4,19,31} These results demonstrated that despite the continuous application of nitrogen to tea, the mature leaf nitrogen content did not vary from the levels observed in short term experiments. However, such mature leaf nutrients levels tend to fluctuate with season of production.³³

Mature leaf phosphorus declined ($p \leq 0.05$) with increasing nitrogenous fertilizer rates (Table 2), as had been observed in short term experiments.^{4,8,10,11,19,23,31} This could be due to soil phosphorus fixation with reducing pH.³⁴ Phosphorous level in mature leaf below 0.15% is considered deficient.^{9,24,30} Long term application of NPK fertilizer beyond 50 Kg N induced phosphorous deficiency in the tea. Compared to short term experiments,^{4,10,11,19,31} the decline was much more with continuous long term application. The decline in phosphorous levels occurred despite increasing phosphorous application with the compound NPK fertilizer formulation used in the trial. The recommended technology of correcting phosphorous deficiency is through remedial application of phosphatic fertilisers. These results demonstrated that phosphorous deficiency caused by change in the soil acidity arising from nitrogenous fertilizer application cannot be corrected by remedial application of phosphatic fertilizer. Such deficiencies may need to be corrected by change of fertilizer regimes such as use of organic fertilisers.^{13,17}

Mature leaf potassium significantly reduced ($p \leq 0.05$) with increasing nitrogenous fertilizer rates (Table 2). Such decline had also been noted in short term fertilizer trials.^{4,11,19,31} The decline was due to reduced soil pH which enhanced potassium leaching.³⁵ The control (0 kg N ha⁻¹ year⁻¹ treatment had potassium level that was below 1.2% that is considered deficient in the nutrient.^{24,30} These levels declined further with increasing rates of nitrogen fertilizer. Long term nitrogenous use, especially rates above 100 kg N ha⁻¹

Table 1: Critical levels of nutrients in the uppermost mature leaf

Nutrient	Deficient	Borderline	Adequate
Nitrogen	Below 3.0%	3.0 to 3.5%	Above 3.5%
Phosphorus	Below 0.15%	0.15 to 0.17%	Above 0.17%
Potassium	Below 1.2%	1.20 to 1.50%	Above 1.50%
Magnesium	Below 0.10%		
Zinc	Below 10 ppm		

Source: Owuor and Wanyoko³⁰

Table 2: Changes in mature leaf macronutrients contents due to long term application of high rates of nitrogenous fertilizers

Nitrogen rate (kg N)	Macronutrients					
	%N	%P	%K	%Ca	%Mg	%Mn
0	2.98	0.17	1.17	0.77	0.09	0.11
50	3.58	0.16	1.15	0.87	0.09	0.17
100	3.67	0.13	1.13	0.70	0.06	0.30
200	3.85	0.12	1.07	0.56	0.03	0.38
400	3.93	0.11	1.06	0.56	0.04	0.39
800	4.13	0.11	1.04	0.51	0.03	0.43
CV (%)	1.0	1.8	1.1	10.7	10.4	0.03
LSD, (p0.05)	0.07	0.01	0.02	0.13	0.01	4.6



year⁻¹, induced potassium deficiency that needed correction. In tea production, potassium deficiency is corrected through remedial application of the nutrient.²⁴ In short term experiment on seedling tea, staggering nitrogen and potassium fertilisers application to help improve potash uptake at high rates of nitrogen did not improve the leaf potassium content.^{23,36} These results demonstrated that induced potassium deficiency by application of nitrogenous fertiliser may not be corrected by the remedial potash application. It may be necessary to first correct soil factors responsible for the potash decline, including reducing soil acidity.

Mature leaf calcium and magnesium decreased ($p \leq 0.05$) with increase in nitrogenous fertilizer rates (Table 2). In the previous short term studies, mature leaf magnesium levels showed no responses to increase in nitrogen fertiliser application rates.^{4,10,11,19,23} However, high rates of nitrogen on clone S15/10³⁷ and clone TRFK 6/8 planted in different locations within East Africa, had sporadic responses with some sites showing no response while others recorded decline in mature leaf magnesium contents.^{4,31} In this study, high rates of 100 kg N and beyond reduced ($p \leq 0.05$) mature leaf magnesium content. The reduction was more pronounced at higher rates of nitrogen. Mature leaf magnesium levels below 0.10% is considered deficient.^{24,30} Including the control plot, long term application of high rates caused high magnesium deficiency in the seedling tea, the deficiency being more severe at higher rates of application (Table 2). Long term high rates of nitrogen therefore caused decline in mature leaf magnesium level that may make the plants have low ability to photosynthesise. In the long run, this may make the tea plantations moribund.

Limits to guide mature leaf calcium levels in tea nutrition advisory system has not been set. But it is generally accepted that increase in soil acidity reduces calcium availability to plants. Although there were no significant changes in mature leaf calcium content from 0 to 100 kg N, there was decline ($p \leq 0.05$) in the levels at rates beyond the 100 kg N ha⁻¹ year⁻¹ (Table 2). Notably, the calcium levels at rates from 200 to 800 kg kg N ha⁻¹ year⁻¹ were also not different. Previous studies had recorded declining mature leaf calcium levels with increasing nitrogen fertiliser rates that tended to level up at high rates.^{4,10,11,19,37} These changes in mature leaf were attributed to decline of the nutrient in the soil^{3,11} caused by nitrogenous fertiliser increasing soil acidity as calcium is more soluble in alkaline than acidic media.^{11,20}

Mature leaf manganese increased ($p \leq 0.05$) with higher rates of nitrogenous fertilizer application (Table 2). Such increase in leaf manganese with increasing rates of nitrogen had been recorded in previous studies.^{4,11,19,23,32,33} The magnitude of the

changes with long term application of nitrogenous fertiliser was much higher than those recorded in the previous short-term low rates of nitrogen fertiliser rates studies.^{4,11,19,23,33} The long term continuous application of high nitrogenous fertiliser rates could cause accumulation of very high manganese levels in the mature leaves leading to leaf necrosis. These results are demonstrating that long term continuous application of high rates of nitrogen could be causing plant nutrients imbalance that may not be easily corrected in future.

Micronutrients are essential for plant growth. However, apart from zinc (Table 1), their levels have not been set in tea tissues to guide fertiliser use. Indeed, zinc is the only micronutrient regularly applied as part of tea plant nutrition.^{9,24} The levels of selected micronutrients in mature leaves due long term high rates of nitrogen fertiliser applications are presented in Table 3. Except for aluminium and iron, the results showed high coefficients of variations. This may indicate that naturally micronutrient concentrations vary more widely and are less consistently distributed in mature leaf and the soil. Micronutrients are required in very small quantities, so their concentrations in plant tissue are lower, making them more sensitive to variations such that even small environmental differences can lead to large fluctuations.³⁸ The micronutrients availability in acidic tea soils is influenced by soil pH, moisture, organic matter, redox conditions and soil heterogeneity which vary across plots or plants, leading to high variability in uptake and translocation.^{39,40}

The changes in mature leaf boron, copper, lead and sodium with variations in long term high rates of nitrogen were not significant. In previous studies carried out at different locations,^{4,31} copper levels increased ($p \leq 0.05$) with increase in nitrogen fertiliser rate in some locations, while showing no response at other locations. The changes observed therefore indicate mature leaf response to copper were largely influenced by environmental factors and soil geology. However, levels aluminium, barium, iron and zinc changed ($p \leq 0.05$) with rates of nitrogen. Mature leaf aluminium increased ($p \leq 0.05$) with increasing rates of nitrogen. Similar increase had been observed in previous short term nitrogen rates studies.^{21,37} The magnitude of the changes observed in the present study were similar to those observed in the previous short term studies. Iron and zinc levels in mature leaf increased ($p \leq 0.05$) with increase in continuous long term application of high rates of nitrogen. Similar increases had been observed in a short term nitrogenous fertiliser trial on clone TRFK 6/8 in different parts of East Africa.^{4,31} The magnitude of the changes for zinc and iron were however, much higher in the present study. Barium levels declined with long term

Table 3: Changes in mature leaf micronutrients contents due to long term application of high rates of nitrogenous fertilizers

Nitrogen Rate (kg N)	Micronutrients							
	Al (%)	B (ppm)	Ba (ppm)	Cu (ppm)	Fe (ppm)	Na (%)	Pb (ppm)	Zn (ppm)
0	0.29	58	86	26	104	0.17	4	13
50	0.30	55	61	17	123	0.18	4	19
100	0.31	37	60	14	133	0.18	8	19
200	0.32	50	45	17	144	0.14	4	24
400	0.34	51	48	16	174	0.12	5	27
800	0.38	45	37	14	233	0.14	8	25
CV (%)	2.9	46.9	29.3	37.8	7.2	26.0	55.5	18.5
LSD, (p0.05)	0.02	NS	30	NS	20	NS	NS	7

continuous application of high rates of nitrogen fertiliser. This is the first report on mature leaf response to nitrogen fertiliser rates in tea.

The recommended plucking standard in Kenya is two leaves and a bud.²⁴ The macro and micronutrients content of two leaves and a bud (referred to as young leaves in this study) is a fair measure of the amounts of nutrients harvested with crop. For sustained production, lost nutrients need to be replenished.⁹ The changes in young leaves macronutrients with continuous long term application of nitrogenous fertiliser is presented in Table 4.

Although the trends of observed macronutrients in young tea leaves (Table 4) were similar to those in mature tea leaves (Table 2), there were striking differences. Nitrogen, phosphorous, potassium and magnesium were much higher in young leaves than in mature leaves. But calcium and manganese were higher in mature leaves than the young leaves. These results demonstrate that tea plants partition these macronutrients in leaves differently. The young leaves nitrogen, and manganese increased ($p \leq 0.05$) while phosphorus, potassium, calcium and magnesium levels reduced ($p \leq 0.05$) with increase in nitrogenous fertilizer rates. Except for lead, all examined micronutrients were higher in mature leaves (Table 3) than in young leaves (Table 5). Tea plants are therefore partitioning more of these micronutrients in mature leaves than young leaves.

The responses of the micronutrients to long term continuous application of high rates of nitrogen is presented in Table 5. As with the mature leaf macronutrients, the data were characterised with high coefficients of variations demonstrating poor reproducibility of replicated analyses. This demonstrated large sensitivity of the micronutrients to small variations in environmental factors. Nonetheless, except for copper, iron and zinc, the micronutrients

levels were not influenced by the continuous long term application of high rates of nitrogen fertiliser. In a previous study on clonal tea there were increases ($p \leq 0.05$) in young leaves iron and zinc and decrease in copper with increase in applied short term nitrogen fertiliser rates in clone BBK 35.⁴¹ Similarly, increase in young leaves aluminium levels with increase in nitrogen fertiliser had been observed in a previous study.⁴² The difference in responses observed could be attributed to differences in tea cultivars and locations of the studies.

When this trial had run for 8 years, it was demonstrated that significant yield response of seedling tea was limited 200 kg N ha⁻¹ year⁻¹.²² Indeed, despite the use of high rates of nitrogen, there were no response to applied nitrogen in the first three years of the trials. For the mean annual data from 1983 to 1991, the yield response was quadratic reaching a calculated maximum 466 kg N ha⁻¹ year⁻¹. Although the seedling tea used was generally low yielding,²² the data presented here demonstrate that there can be substantial removal of nutrients with crop. This may justify the supplementation of removed essential nutrients,

In conclusion, this study demonstrated that continuous application of high rates of nitrogenous fertilizer on tea is causing nutrients imbalance in both mature and young tea that may reduce plant life and cause unsustainable tea production. Removal of nutrients with crop is also high with continuous application of high rates of nitrogenous fertilizer on tea. In other term studies there were no yield^{6,8,22,43} and quality^{44,45} benefits in black tea production and high rates of nitrogen impacted the environment negatively.⁴⁶ Long term continuous application of high rates of nitrogen should therefore be discouraged in tea production.

Table 4: Changes in young tea leaves (2 leaves + a bud) macronutrients contents due to long term application of high rates of nitrogenous fertilizers

Rate (kg N)	Macronutrient					
	% N	% P	% K	% Ca	% Mg	% Mn
0	4.66	0.27	1.27	0.19	0.12	0.02
50	4.85	0.27	1.16	0.21	0.11	0.03
100	5.00	0.26	1.12	0.21	0.11	0.05
200	5.16	0.25	1.08	0.12	0.08	0.11
400	5.26	0.24	1.07	0.15	0.10	0.10
800	5.40	0.24	1.05	0.12	0.09	0.11
CV (%)	1.4	3.3	1.6	8.1	0.02	14.1
LSD, (p0.05)	0.07	0.02	0.03	0.02	10.2	0.01

Table 5: Changes in young tea leaves (2 leaves + a Bud) micronutrients contents due to long term application of high rates of nitrogenous fertilizers

Rate (kg N)	Micronutrient							
	Al (%)	B (ppm)	Ba (ppm)	Cu (ppm)	Fe (ppm)	Na (%)	Pb (ppm)	Zn (ppm)
0	0.17	64	31	17	70	0.26	12	11
50	0.17	59	20	18	83	0.14	18	12
100	0.17	42	35	13	88	0.24	7	14
200	0.17	69	20	18	108	0.20	11	15
400	0.17	52	30	11	103	0.18	13	21
800	0.17	38	28	10	153	0.21	9	18
CV (%)	2.0	28.1	36.5	19.5	12.4	22.6	44.5	13.4
LSD, (p0.05)	NS	NS	NS	5	23	NS	NS	4



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