
Optimization of *Camellia sinensis* Crop Productivity by Use of Blended Fertilizers

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Abstract: Tea (*Camellia sinensis*) is the top foreign exchange earner in Kenya. Its demand is relatively high and this has triggered increased production. Manufacturing companies have also stiff competitions amongst themselves on the aspect of branding. However, for quality assurance and high productivity, the nature of fertilizer in regard to its nutrients has played a major role. This study investigated the effects of blended NPK (Nitrogen:phosphorus:potassium) fertilizer on tea crop productivity in different growing regions of Kenya. The optimum sustainable rate of fertilizer application was also determined. Different rates of 0, 75, 150 and 225 Kg/ha/Yr (kilogram per hectare per year) were used. A randomized complete block design was applied and the sample clone was Tea Research Foundation of Kenya (TRFK) 6/8. The samples, composed of two leaves and a bud, were randomly picked, dried and ground into powder. Each sample was heated to ash in a muffle furnace, cooled and digested using 50% double acid of HNO₃ and HCl with H₂O₂. Desorption was done using HCl and samples allowed to settle before being aspirated into an Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OPS). They were reweighed and digested for determination of total percentage nitrogen.; This was followed by distillation before titration with ammonium borate solution and HCl. Data analysis was done using MSTAT statistical package. The results revealed that the percentage accumulation of elements was highest when blended fertilizer was applied at a lower rate of 75 Kg N/Ha/Yr. compared to standard compounded fertilizer, which required higher rates of up to 225 Kg N/Ha/Yr. for accumulation of nutrients. Blended fertilizer was therefore found to be more economical and highly yielding than Standard compounded fertilizer, as a lower rate of application still led to higher accumulation of elements which is directly proportional to higher yield and quality in tea.

Keywords: *Camellia Sinensis*, Fertilizer, Tea, Productivity, Desorption

1. Introduction

Kenya is a major producer of black tea (*Camellia sinensis*). Currently, it is ranked first before China and India in tea production. The country's tea has won international acclaim for its taste and aroma [1]. It has been proved to have higher levels of antioxidants [2, 3, 4]. Consequently, there is stiff competition among companies when it comes to brand [5].

One of the best bet practices for intensive production of tea is regular application of fertilizers. [6, 7, 8]. Tea fertilizers is available commercially in many physical and chemical forms

[9]. Among these are the compound granular fertilizers which contain all of the plant nutrients specified in each granule, and the blended granular fertilizer which is a mixture of dry fertilizer granules or pills or chips, which have no chemical reaction [10, 11]. Each physical form of the fertilizer has its own uses and limitations, which provide the basis for selecting the best fertilizer for specific crops or location [9].

The quality of tea also influences both local and international markets. The parameter mainly depends on the standard of the green leaf, and this is affected by the type of fertilizer used [5]. Hence, there is need for evaluation of blended fertilizers to establish their effectiveness in order to fully adopt them. In this study, a blended NPK (nitrogen,

phosphorus, potassium) Fertilizer with a formulation of 29:5:5 from one of the leading fertilizer producing companies in Kenya, MEA, was evaluated. Fertilizer blending (bulk blending) is a technical process that offers a customized balance by adjusting fertilizer inputs to crop requirements. In the right proportion, the blend must provide Major nutrients (nitrogen, phosphorus, potassium), Secondary nutrients (calcium, sulphur, magnesium, sodium) and micro-nutrients (iron, manganese, molybdenum, copper, boron, zinc, cobalt [12].

Although Kenya is the leading producer of tea, processing costs compounded with lowered prices discourage growers. Hence, farmers continually seek better production techniques which would increase yields and reduce the costs of production. Some of these techniques include Best Management Practices (BMP) for fertilizer application. This is because fertilizer is the second most expensive input after plucking costs [13]. Thus, in order to make fertilizer favourable, it would be prudent to use readily available fertilizer formulations with high efficacy. The study focused on effects of MEA blended NPK fertilizer (29:5:5) formulation on the yield and nutrients of *Camellia sinensis* crop compared to the standard compounded fertilizer NPK (25:5:5) formulation [9].

Mineral substances contained in green *Camellia sinensis* leaf and in finished products, constitutes about 5-6% of dry matter. Among them are potassium, phosphorus, calcium, magnesium, Sulphur, iron, manganese and fluoride [14]; [15]; [16]. There is a direct correlation between the quality of tea and the content therein of soluble mineral substances. For instance, studies indicate that high rates of sulphate of ammonia improve the quality of green *Camellia sinensis* [16]. With the aging of the plant, total number of minerals increases while the most valuable part of the soluble mineral substances reduces [16]. The potassium content in the *Camellia sinensis* leaf is 50-60% of all mineral substances. The crop has a moderate to high requirement for potassium [17].; However, high levels of potassium reduces the amounts of aflavins and arubigins in leaves leading to reduction in quality [17].; Phosphorus content in *Camellia sinensis* ranges from 15-20% of weight of all mineral substances [15]. The top two-leaves-and-bud part (2+B) has higher content of phosphorus compared to the lower coarse of the leaves and stems [18].

Nitrogen is a critical nutrient for *Camellia sinensis* production as yield depends mainly on the *Camellia sinensis* foliage [19]. Yields increase with increased use of nitrogen fertilizer up to optimum levels, with proportional increase in economic returns [5]. Optimal Nitrogen rates of *Camellia sinensis* vary depending on clones, location and usually range from 75 to 150 Kg N/ha/yr. However, it has been reported that the quality of made tea from clones and hybrid seedlings is highest at a nitrogen application level of 100Kg N/ha. As Nitrogen levels increased above this level the quality decreased [16]. Caffeine content in *Camellia sinensis* has been reported to increase in line with growth rate, which is also influenced by application of Nitrogen and Potash fertilizers [2]. Its availability affects yield of *Camellia*

sinensis, and its applications should be carefully managed, to optimize marketable yield while minimizing environmental effects.

The range of NPK formulae already familiar to the Kenyan *Camellia sinensis* industry (25:5:5) [9], contain nitrogen in two forms, ammonium and nitrate, often in the ratio 2:1. It is not known whether the forms of these nutrients, have any influence on the value for *Camellia sinensis*. In the current situation where compound fertilizers are available at varying formulations and competitive prices, it is not envisaged that farmers would like to make their own mixtures. In addition, there is a commercial company (MEA Ltd), which specializes in the bulk blending of fertilizer and can produce any formulation desired by the farmer [20, 21]

2. Materials and Methods

2.1. Study Area

The research study was conducted in one of the Kenya Agricultural and Livestock Organization (KALRO) institutes, Tea Research Institute (TRI) in Kericho County.

2.2. Research Design

A completely randomized block design of a 10 by 8 plot size with 80 plants per plot, including guard rows [99 plants] with three replications of each fertilizer rates: 0, 75, 150, and 225kg N/ha/year, was used. The clone which was planted in Kericho was TRFK 6/8 with spacing of 5x2.5 ft. the experimental treatments are shown on tables 2 and 3.

Table 1. Experimental treatments.

Fertilizer rate Kg N/ha	Treatment Code	
	MEA blended NPK 29:5:5 formulation	Standard compounded NPK 25:5:5 formulation
0	NPK 0 (1M)	NPK 0 (1S)
75	NPK 75 (2M)	NPK 75 (2S)
150	NPK 150 (3M)	NPK 150 (3S)
225	NPK 225 (4M)	NPK 225 (4S)

Key: M-ME; S-standard

Table 2. Experimental Plan and Treatment randomization.

Plot (rep 1)	Code	Plot (rep 2)	Code	Plot (rep 3)	Code
1	4M	9	2S	17	1M
2	2S	10	1M	18	3S
3	1M	11	4S	19	3M
4	4S	12	2M	20	1S
5	3M	13	3S	21	2M
6	3S	14	4M	22	2S
7	2M	15	1S	23	4M
8	1S	16	3M	24	4S

2.3. Collection of Samples

A total of 16 *Camellia sinensis* samples were used for the research study. The leaf samples were collected in the Field No. 5B in Tea Research Institute (TRI)-Kericho by hand plucking of 2 leaves and a bud of young *Camellia sinensis*, in conformity with standard practice of Good Agricultural

Practice (GAP), from plot No. 217 to plot No. 240 randomly. In addition, mature leaves were sampled randomly from plot No. 241 to plot No. 264 and each sample was registered as per the plot where it was collected. All the samples had undergone different rates of fertilizer treatments (0, 75, 150 and 225 Kg N/Ha/Yr.) for both MEA Blended NPK 29:5:5 fertilizer formulation and standard compounded NPK 25:5:5 fertilizer formulations.

2.4. Determination of Elements *Camellia Sinensis*

The green fresh leaves were dried using an oven for 48 hours at 100° then milled using a coffee miller until fine particles were obtained. 0.1g of each milled sample was weighed and put in a muffle furnace at 450°C for 4 hours 30 minutes to ash completely. Digestion solution was prepared by mixing 20 mls of 50% HCl and 20 mls of 50percentage HNO₃ i.e. 1:1 ratio, 60 mls of 20percentage hydrogen peroxide was then added to the mixed acid. This made a ratio of mixed acid to hydrogen peroxide that was 2:3. 0.5 ml of digesting solution was added to each ashed sample and were then taken to the hot plate for evaporation to dryness. 25 ml of 0.005N HCl was added to each sample and were then allowed to desorb for five hours. 2 ml of each sample solution was pipetted into 25ml volumetric flask and 2.5 ml of strontium solution was then added to each sample in the volumetric flask and topped up to the mark with distilled water. The sample solution in 25 ml volumetric flask was poured into teflon flasks and finally taken to the Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) for determination of major elements.

2.5. Digestion of Samples

0.1 g of the dry powdered samples was weighed using an electric weighing balance and transferred into clean dry Kjeldahl flasks. 1 ml Analar conc. H₂SO₄ was added to each Kjeldahl tube containing the sample, followed by approximately 0.06g of powdered catalyst (1 spatula head) and arranged in Kjeldatherm Vapodest 50s digestion block for digestion of the samples. Digestion of the samples took 31½ hours. The flasks were removed from the digester and cooled. 2ml of distilled water was then run evenly down the neck to wash off deposits down the tubes.

2.6. Distillation of Samples

Markham Still Apparatus was set up and steamed before use. The content of the Kjeldahl tubes (digested sample + 2ml distilled water) was shaken thoroughly and poured into the reservoir and allowed to run into the still by lifting up the stopper. The reservoir was washed with 2ml of distilled water while raising the stopper to allow the washing into the still. The stopper was cautiously replaced firmly and 10ml of 40percentage NaOH solution was poured into the reservoir before lifting it, and the hydroxide (caustic soda) was run into the still and quickly replaced with the stopper to avoid the ammonia gas escaping after which water was finally poured into the reservoir. Ammonia was distilled into the

100ml conical flasks containing 5ml of 2% boric acid solution, 2 drops of indicator and 10ml of distilled water mixed together. When approximately 50ml of distillate had been collected, the conical flask was lowered and then the outside of the condenser tube was rinsed into the flask. The distillate was then ready for titration. The process of distillation; continued until all the samples were finished. The blank was prepared by dissolving the catalyst in 1ml of concentrated Sulphuric acid and heated until the catalyst had dissolved. It was removed and cooled after which 2ml of distilled water was then added and the solution was distilled. The sample distillate was subjected to titration as follows. 0.3g Analar borax was weighed accurately and dissolved in distilled water then diluted to 50ml. 10ml of borax solution was pipetted into a conical flask, and 1 drop of the Conway indicator was added into the flask and titrated with HCl (N/28 HCl). The end point was judged by comparing the color change with the color of 50ml of reference solution plus one drop of Conway indicator. HCl was run until the two solutions showed the same color. N/28 HCl was run into the sample distillate in the conical flask until the indicator just turned pink. The blank distillate was titrated last.

2.7. Data Analysis

The data obtained was analyzed using MSTAT statistical package and Microsoft Excel for calculation of averages and graphical representation.

3. Results and Discussion

Table 3 below shows the accumulation of nitrogen phosphorus and potassium in two-leaves-plus-bud (2+B) samples. These results were also presented in form of a bar graph as shown in figure 1.

Based on these the results, the highest percentage accumulation of nitrogen in the two leaves and a bud samples occurred when MEA blended fertilizer NPK 29:5:5 formulation was applied at the rate of 75 Kg N/Ha/Yr. and when the Standard compounded fertilizer 25:5:5 formulation was applied at the rate of 150 Kg N/Ha/Yr.

Table 3. Accumulation of nitrogen, phosphorus and potassium in two-leaves-and-bud aerial part of *Camellia sinensis*.

Fertilizer type	MEA		STD
	Fertilizer rates		
Nitrogen (N)	0	4.212	4.090
	75	4.227	3.387
	150	4.192	4.017
	225	4.021	4.003
Phosphorus (P)	0	0.843	0.900
	75	0.927	0.873
	150	0.847	0.847
	225	0.853	0.927
Potassium (K)	0	1.940	2.120
	75	2.367	2.243
	150	2.167	2.013
	225	2.110	2.54
Mean fertilizer type		2.392	2.330

Nitrogen in the MEA Blended fertilizer accumulated at a lower rate compared to that of the standard NPK fertilizer (figure 1). This is, therefore, more economical to any *Camellia sinensis* grower. Moreover, higher accumulation of nitrogen in the two leaves and a bud has a great impact to *Camellia sinensis* yield, as nitrogen is responsible for the vegetative growth of the crop to enable growth of more tender shoots that will be plucked. Furthermore, it was observed that the highest percentage accumulation of Phosphorus in the two leaves and a bud was when MEA blended fertilizer was applied at the rate of 75 Kg P/Ha/Yr compared to Standard compounded Fertilizer applied at the rate of 225 Kg P/Ha/Yr (table 3). Besides, its impact on normal growth and maturity, accumulation of Phosphorus at a lower rate is still economically viable to any *Camellia sinensis* farmer.

The highest percentage accumulation of Potassium in two leaves and a bud was when MEA blended fertilizer was applied at the rate of 150 Kg K/Ha/Yr. which is a lower rate too compared to that of Standard fertilizer which was applied at the rate of 225 Kg K/Ha/Yr. to bring the same effect (figure 1). This accumulation further increases plant resistance to diseases allowing the farmer to harvest more.

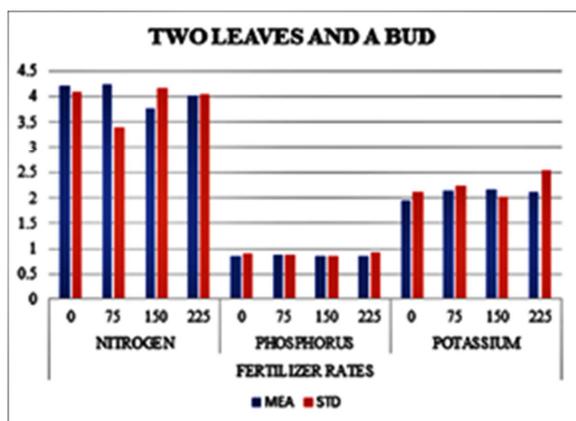


Figure 1. Graphical representation of results for two leaves and a bud samples.

There was an equivalent highest percentage accumulation of Nitrogen in mature leaf samples for fertilizers at the rate of 225 Kg N/Ha/Yr (table 4 and figure 2). This implies that nitrogen only accumulated in the mature leaf after a longer period of fertilizer application or with a higher rate of treatment. Accumulation of nitrogen on the mature leaf has very little significance on the yield of *Camellia sinensis*. Its significance comes in during Nitrogen mobility from the mature leaves to the tender shoots, where it will then lead to vegetative growth of the tender shoots for higher yield. Therefore, this has minimal if no negative economic impact to the farmer.

The highest percentage accumulation of Phosphorus and Potassium in mature leaf was when MEA blended fertilizer was applied at a lower rate of 75 Kg P/Ha/Yr. than that of Standard fertilizer which was applied at the rate of 225 Kg P/Ha/Yr.

Table 4. Accumulation of nitrogen, phosphorus and potassium in mature leaves.

Fertilizer type	MEA		STD
	Fertilizer rates		
Nitrogen (N)	0	2.992	2.547
	75	2.714	2.727
	150	2.173	2.770
	225	2.985	3.053
Phosphorus (P)	0	0.725	0.660
	75	0.943	0.633
	150	0.986	0.627
	225	0.650	0.647
Potassium (K)	0	1.940	2.120
	75	2.219	2.243
	150	2.867	2.013
	225	2.110	2.540
Mean fertilizer type		1.942	1.882

Generally, the highest percentage accumulation of the Standard fertilizer in two leaves and a bud were those of Phosphorus and Potassium, while the lowest percentage accumulation of the standard fertilizer in two leaves and a bud was that of Nitrogen. This negatively affects the yield of *Camellia sinensis* as Nitrogen is responsible for vigorous vegetative growth to obtain more tender shoots that are hence plucked and the lower the Nitrogen accumulation, the lower the yield and quality.

MEA blended fertilizer, unlike the Standard fertilizer, allowed for the accumulation of Nitrogen in the tender shoots (two leaves and a bud). This is important because accumulation of more nitrogen in the tender shoots that are plucked, leads to production of high quality *Camellia sinensis*, higher *Camellia sinensis* yield and vigorous vegetative growth with a greener color.

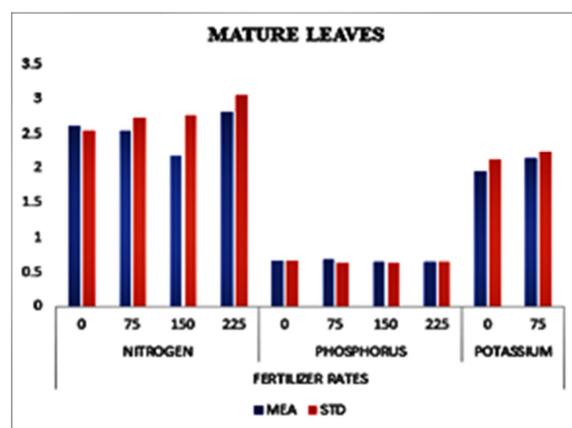


Figure 2. Graphical representation of results for mature leaf samples.

From the mean obtained, as shown in the tables 3 and 4, MEA blended fertilizer had a higher mean of percentage accumulation of nutrients in both 2 + B and mature leaf samples, which is directly proportional to higher yields. Furthermore, table 3 showed that there was highest percentage accumulation of elements in the two leaves and a bud when it was treated with MEA Blended fertilizer at the rates of 75, 75 and 150 Kg N/Ha/Yr. whereas when the two leaves and a bud were treated with Standard fertilizer, there

was highest percentage accumulation of elements in the following treatment rates; 150,225 and 225 Kg N/ha/year.

Highest percentage accumulation of elements in the mature leaf when treated with MEA blended fertilizer, was seen in the following treatments; 225, 75 and 75 Kg N/ha/Yr. whereas when the mature leaf was treated with Standard fertilizer, the highest percentage accumulation of elements was seen in the following treatments; 225,225 and 150 Kg N/ha/Yr. This means, there was highest percentage accumulation of elements in the 2 + B when MEA blended NPK 29:5:5 fertilizer was applied at an average lower rate of 75 Kg N/ha/Yr. compared to Standard compounded NPK 25:5:5 fertilizer which required averagely higher rates of treatment of up to 200 Kg N/ha/Yr. for accumulation. MEA Blended fertilizer averagely accumulated in the mature leaf at a rate of 125 Kg N/ha/Yr. while STD fertilizer accumulated at a rate of 200Kg N/ha/Yr.

Lastly, previous findings on NPK Fertilizer application have shown that the quality of made tea is highest when NPK fertilizer is applied at a rate of at most 100 Kg N/ha/Yr.; From the results above, MEA Blended fertilizer was found to be closer to this rate compared to the Standard fertilizer which was double.

4. Conclusion

In conclusion, MEA Blended fertilizer is highly yielding yet more economically viable than the Standard compounded fertilizer, as there is higher percentage accumulation of elements when the MEA blended fertilizer is applied at an average lower rate of 112 Kg N/ha/Yr. compared to Standard compounded fertilizer, which had to be applied at an average treatment of 200 kg N/ha/Yr. to bring the same effect. A sustainable rate of 75 Kg N/ha/Yr. was also obtained for the MEA Blended fertilizer, as it is closer to the recommended rate of NPK Fertilizer application of 100Kg N/ha/Yr.

Tea growers should take into consideration the use of Blended NPK 29:5:5 fertilizer formulations for higher yields at a lower cost of production. Additionally, further studies should be done on the blended fertilizers with different fertilizer formulations to optimize productivity of *Camellia sinensis*.

List of Abbreviations and Acronyms

2 + B	2 leaves and a bud
TRI	Tea Research Institute
TRFK	Tea Research Foundation of Kenya
ICP-OES	Inductively Coupled Plasma - Optical Emission Spectrometer
KALRO	Kenya Agricultural and Livestock Research Organization
NPK	Nitrogen: Phosphorus: Potassium
STD	Standard
LSD	Least Significant Differences
C.V	Coefficient of Variance
GAP	Good Agricultural Practices

BMP	Best Management Practices
KTDA	Kenya Tea Development Agency
N/ha/Yr	Nitrogen Per Hectare Per Year
P/ha/Yr	Phosphorus Per Hectare Per Year
K/ha/Yr	Phosphorus Per Hectare Per Year

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