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Effect of organic and inorganic fertilizers on growth, yield and nutrient use efficiency of clonal tea (*Camellia sinensis*)

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Abstract. *Mokaya BN, Chemining'wa GN, Ambuko JL, Nyankanga RO. 2018. Effect of organic and inorganic fertilizers on growth yield and nutrient use efficiency of clonal tea (*Camellia sinensis*). Cell Biol Dev 2: 15-26.* This research observed how to boost tea yields in small-scale tea producers using inorganic NPK fertilizers yearly while the cost of fertilizers has been rising, resulting in a decrease in net returns. The influence of different rates of organic and inorganic fertilizers on the soil chemical characteristics, growth, yield, and nutrient usage efficiency of clonal tea was investigated in an experiment. In the 2014/2015 production year, experiments were put up in Kianjokoma, Embu County. Organic Rutuba® and inorganic NPK fertilizers were employed (26.5.5). No-fertilizer control, 625 kg NPK/ha, 937.5 kg NPK/ha, 1875 kg NPK/ha, 625 kg Rutuba/ha + 625 kg NPK/ha, 625 kg Rutuba/ha, 937.5 kg Rutuba/ha, and 1875 kg Rutuba/ha were the treatments. These treatments were repeated three times in a randomized full-block design. Green leaf yield, black made tea yield, leaf length, and leaf breadth were among the crop statistics obtained. The soil data collected at the trial included the pH, exchangeable acidity, organic carbon, micronutrients, and macronutrients. Plant utilization efficiency for nitrogen, phosphate, and potassium were also measured. The cost and net revenue of each fertilizer treatment were calculated as well. The data were subjected to analysis of variance, and the least significant difference test was used to separate the groups at p 0.05. Adding organic Rutuba to the soil raised the pH and the amounts of Mn, Cu, Fe, Zn, Ca, and Mg. Compared to the no-fertilizer control and farmers' practice, the application of 625 kg Rutuba/ha + 625 kg NPK/ha resulted in enhanced leaf length, breadth, fresh green leaf yield, and made tea yield. According to the findings, the application of Rutuba fertilizer considerably improved agronomic efficiency, apparent nutrient recovery, and partial factor productivity of N, P, and K compared to inorganic NPK fertilizer. The study also found that applying NPK 26.5.5 at rates more than 625 kg/ha did not affect growth, yield, nutrient usage efficiency, or net returns. However, because organic Rutuba has a low macronutrient level, the study indicated that it should not be used alone in tea manufacturing. More research is needed to discover the best NPK and Rutuba fertilizer mix, as well as the influence of organic Rutuba fertilizer on tea quality.

Keywords: *Camellia sinensis,* fertilizers, growth, yield, nutrient use, tea

INTRODUCTION

The economy of Kenya is heavily reliant on agriculture, which accounts for 25% of the country's GDP and 75% of its industrial raw materials (MOA 2013). Furthermore, the sector accounts for 65 % of the total exports of Kenya, 18 % of formal and informal job opportunities, and 60 % of total employment chances (MOA 2013). Forestry, fisheries, livestock, food crops, horticulture, and industrial crops are part of the agricultural industry. Tea is one of the most important industrial crops (*Camellia sinensis* L.). Tea contributes 4% of the national GDP and 26% of overall export revenues in Kenya, according to the Tea Board of Kenya (TBK) (Tabu et al. 2015). According to TBK, Tea brought in Ksh.114 billion in export earnings and Ksh.22 billion in local sales in 2013 (TBK 2013), while it brought in Ksh.94 billion in export earnings and Ksh.123 billion in local sales in 2014 and 2015 (KNBS 2016). Tea is also significant for providing direct employment to over 639,521 farmers, as well as various job opportunities along the value chain (Onduru et al. 2012) and the development of rural infrastructure.

Next to water, tea is the most popular and cheapest beverage in the world (Onduru et al. 2012), and it is a major commercial crop in both subtropical and tropical climates. Tea is grown on plantations throughout the world, but in Kenya and Sri Lanka, small-scale farmers play a crucial role (Onduru et al., 2012). China, India, Sri Lanka, and Kenya are the world's top tea producers (Gunathilaka et al., 2016). India is the world's largest producer of black tea, accounting for 25% of global production, with China and Kenya following closely behind (Gunathilaka et al., 2016). India consumes 21% of the world's tea production, with approximately 70% of the tea consumed in the country, while Kenya exports most of its tea (Gunathilaka et al. 2016).

Tea was initially introduced to Kenya in the early twentieth century by the Caine brothers in Limuru in 1904, but commercial manufacturing did not commence until 1924. (Owuor 2011; Kagira ,2012). Tea cultivation is supported by a wide range of ecological variables, all of which significantly impact the rate of growth and quality of the tea plant, resulting in different yields and quality of tea in different places. Tea is grown in Kenya on the foothills of the Aberdare ranges in the west and Mount Kenya in the east of the Great Rift Valley (Owuor 2011). Drought, temperature, frost, high radiation, and soil pH are all factors that affect tea yield and quality. Tea is grown in warm, humid tropical regions with soils ranging from loamy to volcanic red clays with reasonably evenly distributed rainfall throughout the year (Owuor 2011). It grows best in deep, well-drained soils with a pH of 4.0-5.0. (Mwaura et al. 2007). The particular goals of the study were (i) to assess the influence of various rates of inorganic NPK and organic Rutuba fertilizers on soil nutrients in a clonal tea field; (ii) to determine the effect of different rates of inorganic NPK and organic Rutuba fertilizers on clonal tea growth and yield; and (iii) to determine the effect of varying rates of inorganic NPK and organic Rutuba fertilizer on clonal tea growth and yield.

MATERIALS AND METHODS

Description of the experimental sites

Kianjokoma, Embu county agroecological zone (AEZ) UM1 (Sombroek et al. 1984), is 20 kilometers from Embu town and 152 kilometers from Nairobi, in which the experiment was set up. The trial lasted from June 2014 to June 2015, throughout the production of 2014/2015. The site is located at latitude $0^0 23^0$S and longitude $37^0 17.3^0$E, on the tea-growing slopes of Mt. Kenya, at an elevation of 1,831m above sea level. The average temperature at the site is 17.4 to 24.5^0 Celsius, with an annual rainfall of 700 to 900 millimeters. The site experiences a bimodal rain pattern, with long rains in April and May and brief rainfall in October and December. Red clays, classed as ando-humic nitsols, comprise this area's soils (FAO-UNESCO, 1988). pH, exchangeable acidity, total nitrogen, total organic carbon, phosphorus, potassium, calcium, magnesium, manganese, copper, iron, zinc, and sodium were all measured in the soil (Table 1).

During the study, the rainfall was evenly dispersed. The brief rains occurred between July and December 2014, with November 2014 receiving the most rainfall. In January and February 2015, there was little or no rain, severely influencing the plucking rounds and, as a result, the bush productivity. From March through May 2015, there was a lot of rain, with May 2015 being the wettest month of the year. Table 2 shows the study's rainfall, minimum, and maximum temperatures.

Experimental design, treatments, and crop husbandry

The experiment was carried out three times in a randomized complete block design. The treatments were: 1. No-fertilizer control; 2. 625 kg NPK/ha (26.5.5) (farmer practice); 3. 937.5 kg NPK/ha (26.5.5); 4. 1875 kg NPK/ha (26.5.5); 5. 625 kg Rutuba/ha + 625 kg NPK/ha (26.5.5); 6. Application of 625 kg Rutuba/ha; 7. Application of 937.5 kg Rutuba/ha (Recommendation to farmers); and 8. Application of 1875 kg Rutuba/ha. Each plot included 20 tea bushes spaced 1.5 m apart by 0.762 m apart. The tea bushes of clone TRFK 6/8 were 20 years old and already established. A row of mature-grown shrubs was established between the plots to avoid interaction with adjoining crops. Weeding of the plots was low because the bushes had grown a full cover; therefore, no or few weeds were growing during that time. Weeds around the edges were eradicated by hand before fertilizer was applied. Rutuba® organic fertilizer from Rutuba Bio Agric & Organic Fertilizers CO.LTD was used in the experiment, as well as inorganic NPK 26.5.5. The inorganic fertilizer NPK, 26.5.5 is the sort of fertilizer used by KTDA tea producers to top-dress their tea yearly. Rutuba® fertilizer was subjected to a thorough examination (Table 3).

Table 1. Soil analysis before fertilizer application

Chemical component	Value
Ph	4.39
Exchangeable acidity	0.50
Total nitrogen (%)	0.34
Total organic carbon (%)	3.51
Phosphorus (ppm)	35.00
Potassium (Me%)	0.80
Calcium (Me%)	4.90
Magnesium (Me%)	0.19
Manganese (Me%)	0.24
Copper (ppm)	2.91
Iron (ppm)	62.8
Zinc (ppm)	3.12
Sodium (Me%)	0.22

Table 2. Monthly rainfalls and maximum and minimum temperature at Kianjokoma from June 2014 to June 2015

Month	Monthly rainfall (mm)	Max. monthly temp. (°C)	Min. monthly temp. (°C)
June	59.7	21.4	12.9
July	68.9	25.4	11.7
August	76.5	28.5	12.9
September	150.1	25.4	12.0
October	100.7	23.2	13.3
November	200.7	16.8	14.9
December	154.5	19.2	14.4
January	0.0	16.9	14.1
February	25.3	21.3	15.7
March	150.9	18.7	15.1
April	191.0	17.3	15.7
May	234.4	18.6	14.3
June	50.7	17.1	14.5
Monthly mean	112.6	20.8	14.0

Table 3. Analytical results of the organic Rutuba fertilizer that was used during the experiment

Chemical component	Value
Nitrogen (%)	2.1
Phosphorus (%)	1.0
Potassium (%)	1.2
Calcium (%)	3.1
Magnesium (%)	0.4
Iron (mg/kg)	5233.0
Copper (mg/kg)	26.7
Manganese (mg/kg)	512.0
Zinc (mg/kg)	427.0
pH	8.2
Total organic carbon (%)	2.1

Data collection

The information gathered included soil chemical characteristics, second leaf length, and width, green leaf yield, made tea yield, N P and K use efficiency, and fertilizer regime profitability.

Soil chemical data

Soil samples were collected at random from 30 different locations in the experimental field for laboratory analysis. Before scooping the earth to a depth of 30 cm with a soil auger, roots and other plant wastes were removed. The samples were properly mixed to create a composite sample weighing around 500 g for examination. Next, soil samples were scooped from each plot at a depth of 30 cm using a soil auger at 3 separate sites at the end of the experiment (June 2015) and carefully mixed to generate a composite sample from each plot. The samples were then placed in a plastic bag, labeled, and transferred to the National Agricultural Research Laboratories (NARL) in Nairobi, Kenya, for analysis on the same day. pH, total organic carbon, exchangeable acidity, accessible micronutrients, and macronutrients were all measured in the soil samples.

The elements were extracted in a 1:5 ratio (w/v) with a combination of 0.1 N HCl and 0.025 N H2SO4 after the soil samples had been sieved through a 2 mm sieve. A flame photometer was used to measure sodium, calcium, and potassium. In addition, AAS was used to assess phosphorus, magnesium, and manganese (Mukai et al. 1992).

The calorimetric method was used to estimate total organic carbon. For full oxidation, acidified dichromate was used to oxidize organic carbon in an oven-dried soil sample at 150°C for 30 minutes. Next, the cold digests were given a shot of barium chloride. After carefully mixing the cool digests, they were allowed to sit overnight. Finally, at 600 nm, the carbon concentration was measured using a spectrophotometer (Walkley et al. 1934).

The Kjeldahl method was used to determine the total nitrogen. The soil samples (0.5 mm) were oven dried at 40^0 Celsius and digested with concentrated sulphuric acid comprising potassium sulphate, selenium, and copper sulphate that had been hydrated to approximately 35^0 degrees Celsius. Distillation followed by titration with diluted standards 0.007144N H_2SO_4 was used to estimate total N. (2002) (Okalebo et al.).

Exchangeable acidity was evaluated by heating 5 g of oven-dried soil sample (2 mm) to 40^0C in a 50 ml container, adding 12.5 ml of 1 M KCl, and stirring with a clean glass rod for half an hour. The solutions were filtered using a funnel. Next, five successive 12.5 ml aliquots of 1 M KCl were utilized to leach the solutions. The indicator solution phenolphthalein was added and titrated with 0.1 M NaOH until the first permanent pink hue was achieved. The amount of NaOH used was noted. The available trace elements (Cu, Fe, and Zn) were determined using 0.1 M HCl extraction. The elements were extracted with 0.1 M HCl in a 1:10 (w/v) ratio. AAS was used to determine the elements (Mukai et al. 1992). The pH of the soil was tested using a pH meter in a 1:1 (w/v) soil–water suspension.

Length and width determination

At the time of harvest, a random sample of 100 shoots with two leaves and a bud was collected from each plot's gathered shoots. The length and width of the second leaf were measured with a ruler, and each plot's average length and width were recorded 20 times over 7-10 days, depending on crop availability.

Assessment of yield

Leaf plucking began two weeks following fertilizer application in each area. First, the tea was harvested by hand using the traditional method of harvesting two leaves and a bud every 7-10 days, depending on crop availability, for 20 harvests. Then, weigh and record the plucked leaves. Finally, the calculation below was used to convert the green leaves harvested per plot to made tea (kg/ha/year) (Sitienei et al. 2013). Made tea is the tea that has been manufactured from harvested green shoots, i.e., after withering, fermenting, and drying (De Costa et al. 2007).

$$\text{Made tea yield/ha/year} = \frac{N*a*0.225}{b}$$

Where: **a** is the plant population per hectare, **N** is the green leaf yield per plot, **b** is the number of tea bushes per plot, and **0.225** is the factor converting green leaf to made tea.

Determination of leaf nutrient and nutrient use efficiencies

Each plot received 100 mature leaves for nutritional analysis, which calculated nutrient utilization efficiencies. Hydrogen peroxide was used to oxidize the leaf samples at 100^0C. After the breakdown of the excess hydrogen peroxide and evaporation of water, the digestion was completed with concentrated H2SO4 at 330^0C using SE as a catalyst. Nitrogen was then determined using distillation and titration with standardized 0.3 N HCl. Potassium, phosphorus, and nitrogen concentrations were determined using a flame photometer, spectrophotometry, and the Kjeldahl method.

The apparent nutrient recovery, agronomic efficiency, and partial factor productivity of nitrogen, phosphorus, and potassium were calculated. The following equations were used to determine the efficiencies (Sitienei et al., 2013; Jagadeeswaran et al., 2005).

$$\text{Agronomic efficiency (AE)} = \frac{\text{Yield in fertilized plot (kg/ha) -yield in control plot (kg/ha)}}{\text{Quantity of fertilizer nutrient applied (kg/ha)}}$$

Apparent nutrient recovery efficiency (**ANR)** was used to determine the ability of the plant to acquire nutrients from the soil.

ANR= Nutrient uptake in the fertilized plot (kg/ha)-Nutrient uptake in control plot (kg/ha) Quantity of fertilizer nutrient applied (kg/ha)

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration*dry matter Dry matter-Kg of made tea/ha}}{}$$

Partial factor productivity (P_fP)

$$P_fP = \frac{\text{Yield of made tea (kg/ha)}}{\text{Amount of fertilizer nutrients applied (kg/ha)}}$$

Determination of the economic benefits of the treatments

Each fertilizer regime's total expected cost and income were computed to determine each application's profit. The overall cost included the price of fertilizer, the cost of fertilizer application, and the cost of plucking/harvesting. The entire revenue includes the farm gate fee, which is paid monthly for each delivered green leaf, and the annual payment, which varies per factory. One kg was assessed at Ksh. 14/= as the farm gate price per kg of total green sent to the factory in a month, the price paid to small-scale farmers affiliated with KTDA for monthly green leaf deliveries. The yearly payment was 35.05/= of the cumulative green leaf in the financial year, which corresponded to the payment made to farmers who brought the green leaf to the Mungania tea factory in the 2014/2015 financial year the experiment was conducted. As a result, the green leaf was evaluated at Ksh.49.05 per kg. The overall cost comprised labor for fertilizer application (Ksh/ha), fertilizer purchase (Ksh/ha), and plucking (Ksh/ha). Labor costs for harvesting were projected to be Ksh.10/= each kg of harvested green leaf.

In contrast, labor costs for fertilizer application were estimated to be Ksh.50 for every 50 kg bag of fertilizer. Therefore, a 50 kg bag of NPK 26.5.5 and Rutuba fertilizer was sold on the market at Ksh.2,250 and Ksh.3,000, respectively. The entire revenue was estimated by multiplying the cumulative number of green leaves by the total amount paid to farmers per kg.

The total cost = the purchasing cost of fertilizer applied + the cost of harvesting + the cost of applying fertilizer.

Total revenue =cumulative green leaf (kg/ha)* Ksh.49.05 Net revenue=Total Revenue-total cost

Data analysis

All data collected were subjected to analysis of variance (ANOVA) using GEN STAT discovery edition 14 software, and means were separated using the least significant difference (LSD) at p=0.05.

RESULTS AND DISCUSSION

Effects on soil nutrients, pH, total carbon, and exchangeable acidity in a clonal tea field at the end of the experiment

Fertilizer treatment regimes significantly affected the soil's pH, exchangeable acidity, total carbon, manganese, copper, iron, and zinc levels ($p \leq 0.05$). (Table 4). The pH value of 1,875 kg Rutuba/ha was considerably higher than the pH value of all other fertilizer rates except 625 kg Rutuba/ha + 625 kg NPK/ha, which was not statistically different from 937.5 kg Rutuba/ha, 625 kg Rutuba/ha, and the no-fertilizer control. There were no significant differences in the rates of solo NPK. The pH of the soil varied between 3.94 and 5.36 (1875 kg NPK/ha). The 1,875 kg NPK/ha application rate resulted in significantly higher exchangeable acidity than the other rates. The exchangeable soil acidity of 625 kg Rutuba/ha + 625 kg NPK/ha, 625 kg NPK/ha, 937.5 kg NPK/ha, 625 kg Rutuba/ha, and the no-fertilizer control were not substantially different. There was no discernible difference in exchangeable soil acidity between the 1,875 kg Rutuba/ha and the 937.5 kg Rutuba/ha treatments. The soil acidity was changeable between 0.3 Me% (1,875 kg Rutuba/ha) and 0.57 Me% (1875 kg NPK/ha). The 1,875 kg Rutuba/ha application exhibited a significantly greater total carbon content than all other fertilizer rates except the 937.5 kg Rutuba/ha application.

There was no significant change in total carbon content between 937.5 kg Rutuba/ha, 625 kg Rutuba/ha, 625 kg NPK/ha, and 625 kg Rutuba/ha + 625 NPK/ha applications. The total carbon content of 1,875 kg NPK/ha, 937.5 kg NPK/ha, and the no-fertilizer control was not substantially different. The total carbon content varied between 2.96 % (control with no fertilizer) to 4.32 % (1875 kg Rutuba/ha). 1875 kg Rutuba/ha application had a considerably greater Mn content than all other fertilizer regimes except the 937.5 kg Rutuba/ha application, which was not statistically different from the 625 kg Rutuba/ha application. The Mn content was not significantly different between the NPK rates and the no-fertilizer control. Mn concentrations ranged from 0.18 Me% (all NPK rates) to 0.33 Me% (1,875 kg Rutuba/ha).

The three sole Rutuba application rates and 625 kg Rutuba/ha + 625 kg NPK/ha exhibited significantly higher Cu content than the sole NPK application rates and the no-fertilizer control. Cu concentration was substantially greater in the no-fertilizer control than in the pure NPK application regimes. Copper levels ranged from 2.28 ppm (1,875 kg NPK/ha) to 4.37 ppm (1,875 kg Rutuba/ha). The application of 1,875 kg Rutuba/ha resulted in the highest Fe content of all treatments. The application of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha resulted in the highest Fe content of all NPK treatments and the no-fertilizer control.

The only application of NPK resulted in a lower Fe concentration than the no-fertilizer control. Fe concentrations ranged from 45.83 ppm (1,875 kg NPK/ha) to 94.5 ppm (1,875 kg Rutuba/ha), and the 1,875 kg Rutuba/ha application showed a considerably greater Zn content than all other rates except 937.5 kg Rutuba/ha. There was no significant difference in Zn concentration between applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha. However, these two treatments contained more Zn than all NPK treatments, the no-fertilizer control and 625 kg Rutuba/ha + 625 kg NPK/ha. The application of 625 kg Rutuba/ha in combination with 625 kg NPK/ha resulted in a significantly higher Zn soil concentration than any other NPK application rate. The zinc soil content was not significantly different for any NPK rates or the no-fertilizer control. Zinc concentrations ranged from 2.45 ppm (625 kg NPK/ha) to 7.99 ppm (1,875 kg Rutuba/ha).

The application regimens unaffected TN and Na content; however, P, K, Ca, and Mg were altered considerably (p 0.05). (Table 4.2). The application of 1875 kg NPK/ha resulted in the greatest P content of all the fertilizer regimes. The P content of applications of 937.5 kg NPK/ha and 625 kg NPK/ha was not significantly different. The P content of 625 kg Rutuba + NPK, 625 kg NPK/ha, 1875 kg Rutuba/ha, and 937.5 kg Rutuba/ha was not substantially different. The P content of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha applications was not significantly different. The no-fertilizer control had the lowest P content compared to all treatments except 625 kg Rutuba/ha. The P content ranged from 23.33 ppm (control) to 65 parts per million (1,875 kg Rutuba/ha).

The three NPK-only applications and the 625 kg Rutuba/ha + 625 kg NPK/ha application rates all exhibited significantly higher K content than the other. There was no discernible difference in the K content of different applications. 625 kg Rutuba + 625 kg NPK/ha, 937.5 kg NPK/ha, 625 kg NPK/ha, and 625 kg Rutuba/ha. The K content was not substantially different between 625 kg Rutuba + 625 kg NPK/ha and all other Rutuba application rates, which were also not significantly different from the no-fertilizer control. The K concentration varied between 0.75 and 1.5 Me percent (non-fertilized control) and 1,875 kg NPK/ha (1,875 kg NPK/ha). All applications of 625 kg Rutuba/ha, 625 kg Rutuba/ha + 625 kg NPK/ha, and 625 kg NPK/ha exhibited significantly higher Ca contents than the other treatments. The Ca content of all NPK rates tested, 625 kg Rutuba/ha+ 625 kg NPK/ha, and the no-fertilizer control were not significantly different. Ca concentration varied between 4.47 Me% (control) to 8.13 Me% (1,875 kg Rutuba/ha). The application of 1,875 kg Rutuba/ha resulted in a significantly higher Mg content than the application of 937.5 kg Rutuba/ha, which resulted in a significantly higher Mg content than all other treatments. The no-fertilizer control had an Mg level that was not substantially different from 625 kg NPK/ha, but was significantly higher than 937.5 kg NPK/ha and 1,875 kg NPK/ha. The Mg content of the three sole NPK fertilizer application rates was not significantly different. The magnesium level varied between 0.21 and 0.55 ppm (1,875 kg NPK/ha and 937.5 kg NPK/ha).

Table 4. Effect of different fertilizer regimes on soil pH, Exchangeable acidity, total carbon, and micronutrients in a clonal tea field at Kianjokoma at the end of the experimental period

Treatments	pH	Ea (Me%)	TC (%)	Mn (Me%)	Cu (ppm)	Fe (ppm)	Zn (ppm)
1,875 kg NPK/ha	3.94[c]	0.57[a]	3.03[d]	0.18[c]	2.28[d]	45.83e	2.70[d]
625 kg Rutuba/ha +625 kg NPK/ha	4.83[ab]	0.47[b]	3.60[bc]	0.23b[c]	4.06[a]	61.27[c]	3.74[c]
937.5 kg NPK/ha	3.98[c]	0.47[b]	3.05[cd]	0.18[c]	2.66[cd]	47.47[e]	2.71[d]
625 kg NPK/ha	4.06[c]	0.43[b]	3.47[bc]	0.18[c]	2.89[c]	49.63[de]	2.45[d]
1,875 kg Rutuba/ha	5.36[a]	0.30[d]	4.32[a]	0.33[a]	4.37[a]	94.50[a]	7.99[a]
937.5 kg Rutuba/ha	4.41[bc]	0.33[cd]	3.92[ab]	0.28[ab]	4.34[a]	76.40[b]	7.43[ab]
625 kg Rutuba/ha	4.27[bc]	0.43[b]	3.63[bc]	0.26[b]	4.01[a]	69.43[b]	6.75[b]
Control	4.71[b]	0.43[b]	2.96[d]	0.19[c]	3.44[b]	54.67[cd]	3.05[cd]
P-value	0.003	0.002	<.001	<.001	<.001	<.001	<.001
LSD p≤ 0.05	0.63	0.10	0.52	0.06	0.46	7.04	0.99
CV%	9	17	8.6	15.5	7.4	6.4	12.3

Note: Treatments with different letters in the same column are significantly different according to LSD at p≤ 0.05; CV: coefficient of variation; Ea: Exchangeable acidity; TC: Total carbon

Table 5. Effects of different fertilizer regimes on total nitrogen, phosphorus, potassium, calcium, magnesium, and sodium in a clonal tea field at Kianjokoma from June 2014 to June 2015

Treatments	TN (%)	P (PPM)	K (Me%)	Ca (Me%)	Mg (Me%)	Na (Me%)
1,875 kg NPK/ha	0.35[a]	65.00[a]	1.50[a]	4.57[b]	0.21[f]	0.25[a]
625 kg Rutuba/ha + 625 kg NPK/ha	0.33[a]	43.33[c]	1.26[abc]	6.73[ab]	0.34[c]	0.35[a]
937.5 kg NPK/ha	0.31[a]	53.33[b]	1.40[ab]	4.80[b]	0.21[f]	0.23[a]
625 kg NPK/ha	0.33[a]	45.00[bc]	1.40[ab]	5.90[ab]	0.23[ef]	0.28[a]
1,875 kg Rutuba/ha	0.38[a]	43.33[c]	0.94[cd]	8.13[a]	0.55[a]	0.40[a]
937.5 kg Rutuba/ha	0.35[a]	36.67[cd]	0.96[cd]	7.90[a]	0.45[b]	0.40[a]
625 kg Rutuba/ha	0.33[a]	30.00[de]	1.02[bcd]	7.57[a]	0.28[d]	0.32[a]
Control	0.32[a]	23.33[e]	0.75[d]	4.47[b]	0.25[de]	0.25[a]
p-value	0.20	<.001	0.01	0.04	<.001	0.31
LSD p≤ 0.05	NS	9.16	0.38	2.67	0.04	NS
CV%	18	12.3	12.8	24.4	7	23

Note: Treatments with a different letter(s) in the same column are significantly different according to LSD at p≤ 0.05; CV: coefficient of variation; TN: total nitrogen; LSD: least significant difference

Effects on the average width and length of the second leaf of the harvestable shoot

In both seasons, fertilizer treatment regimes had a significant (p0.05) effect on the average breadth of the second leaf (Table 6). In the first season, the three solo NPK application rates and the application of 625 kg Rutuba/ha + 625 kg NPK/ha resulted in much wider average widths than the other treatments. The rates of application of the three sole Rutuba were not significantly different. The average width of the second leaf was not substantially different, whether 625 kg Rutuba/ha, 937.5 kg Rutuba/ha, or no fertilizer was applied. In season one, the average width of the second leaf was 1.8 cm (no fertilizer control) to 2.8 cm (625 kg Rutuba/ha + 625 kg NPK/ha). In season two, applications of 625 kg Rutuba+625 kg NPK/ha, 1875 kg Rutuba/ha, and three sole NPK fertilizer rates resulted in significantly wider average widths than all other treatments. The average width of the second leaf did not differ significantly between applications of 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha.

There was no significant difference in the average width of the second leaf between applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha. The average width of the second leaf varied between 1.8 cm (no fertilizer control) and 2.9 cm (625 kg NPK/ha and 625 kg Rutuba/ha + 625 kg NPK/ha) in the second season. In both seasons, the fertilizer treatment regimes had a significant (p0.05) effect on the second leaf length (Table 6). The combination of 625 kg Rutuba/ha and 625 kg NPK/ha, as well as the three NPK application rates, resulted in significantly longer average second leaf lengths than the three solo Rutuba treatments and the no-fertilizer control. The 1875 kg Rutuba/ha application rate resulted in a significantly longer average length than all other Rutuba treatment rates and the no-fertilizer control. The average length of the second leaf did not differ significantly between applications of 937.5 kg Rutuba/ha, 625 kg Rutuba/ha, and the no-fertilizer control. The average length of the second leaf varied between 4.1 cm (control) to 7.4 cm (1,875 kg NPK/ha and 625 kg Rutuba/ha+ 625 kg NPK/ha) in season one. In both seasons, the administration of 625 kg rutuba/ha had no discernible effect on the average length of the second leaf compared to the no-fertilizer control. The length of the second leaf did not differ significantly between the Rutuba treatment rates. Except with 625 kg Rutuba/ha, all solitary Rutuba treatments exhibited significantly longer average leaf length than the no-fertilizer control. The average length of the second leaf ranged from 4.4 cm in the absence of fertilizer to 7.6 cm in the presence of 1,875 kg NPK/ha.

Effects on the green leaf and made tea yields

In both seasons, green leaf and made tea yields differed considerably ($p \leq 0.05$) according to the fertilizer treatment regime (Table 7). In the first season, fertilizer application boosted green leaves and improved tea yields significantly regardless of regime or kind. 625 kg Rutuba/ha + 625 kg NPK/ha produced much more green leaves and made tea than all other fertilizer treatment regimes. The three solo NPK fertilizer rates did not differ considerably in green leaf and made tea yields, but they were significantly greater than the three Rutuba treatment rates. 1875 kg Rutuba/ha and 937.5 kg Rutuba/ha considerably increased green leaf and made tea yields compared to 625 kg Rutuba/ha, which was not significantly different from the no-fertilizer control. Season one green leaf yields ranged from 1521 kg/ha (no fertilizer) to 6587 kg/ha (625 kg Rutuba + 625 kg NPK/ha), while made tea yields ranged from 342 kg/ha (no fertilizer) to 1482 kg/ha (625 kg Rutuba + 625 kg NPK/ha).

In season two, as compared to all other fertilizer regimens, 625 kg Rutuba/ha + 625 kg NPK produced considerably more green leaves and made tea yields (Table 7). The three single NPK rates did not affect green leaf or made tea yields. There were no significant variations in green leaf and brewed tea yields when applied 1,875 kg NPK/ha, 625 kg NPK/ha, or 1,875 kg Rutuba/ha. The three Rutuba application rates did not differ considerably in green leaf and made tea yields, but they were significantly greater than the no-fertilizer control. Season two leaf yields ranged from 2621 kg/ha (no-fertilizer control) to 6444 kg/ha (625 kg Rutuba+ 625 kg NPK/ha), whereas made tea yields ranged from 588 kg/ha (no-fertilizer control) to 1450 kg/ha (625 kg Rutuba+ 625 kg NPK/ha).

Table 6. Length and width (cm) of the second leaf of the harvestable shoot for different fertilizer regimes in the first and second seasons at Kianjokoma from June 2014 to June 2015

Treatments	Season 1		Season 2	
	Average width (cm)	Average length (cm)	Average width (cm)	Average length (cm)
1,875 kg NPK /ha	2.7[a]	7.4[a]	2.7[a]	7.0[a]
625 kg Rutuba/ha +625kg NPK/ha	2.8[a]	7.4[a]	2.9[a]	7.1[a]
937.5 kg NPK/ha	2.7[a]	6.9[a]	2.7[a]	7.1[a]
625 kg NPK/ha	2.7[a]	6.9[a]	2.9[a]	7.2[a]
1,875 kg Rutuba/ha	2.3[b]	5.7[b]	2.6[ab]	5.6[b]
937.5 kg Rutuba/ha	2.0[bc]	4.6[c]	2.2[bc]	5.2[b]
625 kg Rutuba/ha	2.1b[c]	4.5[c]	2.2[c]	4.9[bc]
Control	1.8[c]	4.1[c]	1.8[d]	4.4[c]
p-value	<.001	<.001	<.001	<.001
LSD($p \leq 0.05$)	0.3	0.5	0.4	0.7
CV%	8	4.9	8.5	6.2

Note: Treatments with different letters in the same column are significantly different according to the least significant difference test ($p \leq 0.05$)

Table 7. Green leaf (kg/ha) and made tea yields (kg/ha) under different fertilizer regimes at Kianjokoma from June 2014 to June 2015

Treatments	Season 1		Season 2		Cumulative yield	
	GL	MT	GL	MT	GL	MT
1,875 kg NPK/ha	4162[b]	936 [b]	5339[bc]	1201[bc]	9501[b]	2137[b]
625 kg Rutuba/ha +625 kg NPK/ha	6587[a]	1482[a]	6444[a]	1450[a]	13031[a]	2932[a]
937.5 kg NPK/ha	4105[b]	924[b]	5382[b]	1211[b]	9486[b]	2135[b]
625 kg NPK/ha	4004[b]	900[b]	5296[bc]	1192[bc]	9300[b]	2093[b]
1,875 kg Rutuba/ha	2856[c]	642[c]	4435[cd]	998[cd]	7291[c]	1641[c]
937.5 kg Rutuba/ha	2669[c]	600[c]	4004[d]	901[d]	6674[c]	1501[c]
625 kg Rutuba/ha	1708[d]	384[d]	3660[d]	823[d]	5368[d]	1207[d]
Control	1521[d]	342[d]	2612[e]	588[e]	4133[e]	930[e]
p-value	<.001	<.001	<.001	<.001	<.001	<.001
LSD ($p\leq 0.05$)	362.8	73.53	920.5	207.1	1036	233.3
CV%	5.4	5.4	11.3	11.3	7.3	7.3

Note: Treatments with different letters in the same column are significantly different according to the least significant difference test ($p\leq 0.05$). GL-Green leaf; MT-Made tea; CV: coefficient of variation; LSD: least significant difference

Table 8. Nitrogen, potassium, and phosphorus leaf uptake under different fertilizer regimes at Kianjokoma from June 2014 to June 2015

Treatments	Nitrogen (%)	Potassium (%)	Phosphorus (%)
1,875 kg/ha NPK	3.5[c]	2.4[d]	0.3[de]
625 kg Rutuba/ha + 625 kg NPK/ha	4.5[a]	4.4[b]	0.5[a]
937.5 kg NPK/ha	3.9[b]	2. 6[d]	0.4[cd]
625 kg NPK/ha	4.1[b]	2.7[cd]	0.4[bcd]
1,875 kg Rutuba /ha	3.2[cd]	5.4[a]	0.5[a]
937.5 kg rutuba/ha	3.1[de]	4.8[ab]	0.5[a]
625 kg Rutuba/ha	2.9[e]	3.5[c]	0.5[a]
Control	2.1[f]	2.4[d]	0.3[e]
p-value	<.001	<.001	<.001
LSD $p\leq 0.05$	0.3	0.9	0.1
CV%	4.6	14.4	10.7

Note: Treatments with different letters in the same column are significantly different according to LSD at $p\leq 0.05$; CV: coefficient of variation

Effects on leaf nitrogen, potassium, and phosphorus uptake

Fertilizer application demonstrated a substantial ($p \leq 0.05$) effect on the nitrogen, potassium, and phosphorus content of the leaves (Table 8). When 625 kg Rutuba/ha was combined with 625 kg NPK/ha, the nitrogen content was much higher than when no fertilizer was applied, or other fertilizer regimens were used. There were no significant variations in leaf nitrogen content between 937.5 kg NPK/ha and 625 kg NPK/ha applications, nor between 1,875 kg NPK/ha and 1,875 kg Rutuba/ha applications. The latter treatment was comparable to applying 937.5 kg rutuba/ha. The leaf nitrogen concentration of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha was not substantially different. The N leaf content varied between 2.1 and 4.5 percent (no fertilizer control) and 625 kg Rutuba+ 625 kg NPK/ha. The application of 1875 kg Rutuba/ha resulted in the highest potassium content when compared to the no-fertilizer control and all other treatments, except for the application of 937.5 kg Rutuba/ha, which did not differ substantially from the application of 625 kg Rutuba/ha + 625 kg, NPK/ha. The leaf K content was not significantly different between the three sole NPK application rates and the no-fertilizer control. The leaf K content varied between 2.4 and 5.4 % (no fertilizer control and 1,875 kg NPK/ha). All rates of solitary Rutuba fertilizer and 625 kg NPK/ha + 625 kg Rutuba/ha treatment exhibited significantly higher leaf P content than other fertilizer regimes. There was no statistically significant difference in leaf P content between the solo NPK application rates and between the 1875 kg NPK/ha application and the no-fertilizer control. The P content ranged from 0.3 % (control with no fertilizer and 1,875 kg NPK/ha) to 0.5 % (all sole rutuba applications and 625 kg NPK/ha+ 625 kg Rutuba/ha).

Effects on apparent nutrient recovery, partial factor productivity, and agronomic efficiencies of nitrogen, potassium, and phosphorus in clonal tea

The fertilizer treatment regimes had a significant effect (p0.05) on nitrogen, potassium, and phosphorus apparent nutrient recovery (ANR) (Table 9). The application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha resulted in all treatments' highest apparent nutritional recovery of nitrogen (ANRN). 1875 kg Rutuba/ha application had a considerably greater ANR_N than all other NPK application rates and 625 kg Rutuba/ha + 625 kg NPK/ha application. 625 kg NPK/ha and 625 kg Rutuba/ha + 625 kg NPK/ha had an ANR_N of 625 kg NPK/ha that was not substantially different from 1875 kg NPK/ha, and 937.5 kg NPK/ha, which were not significantly different. The ANR_N varied from 0.11 (1875 kg NPK/ha) and 1.69 (937.5% Rutuba/ha). All Rutuba-only treatments had significantly better apparent nutrient recovery of potassium (ANR_K) than all other fertilizer rates. While in ANR_K, there was no significant difference between 625 kg NPK/ha and 625 kg Rutuba/ha + 625 kg NPK/ha. In ANR_K, the rates of sole NPK application were not significantly different, and in $ANR_{K,}$ values varied between 0.32 (1875 kg NPK/ha) and 4.01 (1875 kg Rutuba/ha). Using 937.5 kg Rutuba/ha and 625 kg Rutuba/ha resulted in a significantly greater apparent nutrient recovery of phosphorus (ANR_P) than any other fertilizer regime. Furthermore, 1,875 kg Rutuba/ha had a considerably higher ANR_P than all other NPK fertilizer rates but was not significantly different from 625 kg Rutuba/ha + 625 kg NPK/ha, which was not significantly different from 625 kg NPK/ha. The application of 937.5 kg/ha NPK was not significantly different from that of 1875 kg/ha NPK and had the lowest ANR_P. The ANR_P was between 0.05 (1875 kg NPK/ha) to 0.52 (937.50 kg Rutuba/ha). The fertilizer regimens considerably affected the nitrogen, potassium, and phosphorus partial factor productivity (PfP) (Table 9). The PfP_N levels were considerably greater when 625 kg Rutuba/ha and 937.5 kg Rutuba/ha were applied, compared to all other treatments. The application of 1875 kg Rutuba/ha resulted in significantly better nitrogen partial factor productivity (PfP_N) than the other NPK treatments, including the application of 625 kg Rutuba/ha + 625 kg NPK/ha, whose PfP_N was not statistically different. The PfP_N concentrations were between 4.38 (1875 kg NPK/ha) and 92.04 (625 kg Rutuba/ha). 625 kg Rutuba/ha significantly increased the partial factor productivity of potassium (PfP_K) compared to all other treatments.

There were no significant variations in PfPk between applications of 625 kg Rutuba/ha + 625 kg NPK/ha, 625 kg NPK/ha, 1875 kg Rutuba/ha, and 937.5 kg Rutuba/ha. The application of 625 kg Rutuba/ha with 625 kg NPK/ha and 937.5 kg NPK/ha did not differ substantially from the application of 625 kg NPK/ha, which did not change significantly from the application of 1875 (NPK/ha. The PfPK concentrations were 22.8 (1875 kg NPK/ha) and 158.39 (625 kg Rutuba/ha). The application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha resulted in considerably greater phosphorus partial factor productivity (PfP_P) than all other treatments. In PfP_P, the application of 1875 kg Rutuba/ha, 625 kg NPK/ha, 937.5 kg NPK/ha, and 625 kg Rutuba/ha + NPK 625 kg NPK/ha did not differ significantly. In partial PfP_P, the applications of 937.5 kg Rutuba/ha NPK and 1875 kg NPK/ha NPK were not substantially different. The PfPP concentrations were between 22.8 (1875 kg NPK/ha) to 195.18 (625 kg Rutuba/ha).

The nitrogen, potassium, and phosphorus agronomic efficiency were significantly ($p\leq0.05$) affected by the fertilizer application regimes (Table 10). Compared to all other fertilizer regimes, applications of 937.5 kg Rutuba/ha and 625 kg Rutuba/ha exhibited the highest agronomic efficiency of nitrogen (AEN). The AEN of 625 kg Rutuba/ha was not substantially different from the AEN of 1875 kg Rutuba/ha or 625 kg Rutuba/ha + 625 kg NPK/ha. In AEN, there were no significant differences in the rates of sole NPK fertilizer and 625 kg Rutuba/ha Plus 625 kg NPK/ha. Nitrogen's agronomic efficiency (AEN) varied between 2.48 (1875 kg NPK/ha) and 29.03 (937.5 kg Rutuba/ha). The treatment of 625 kg Rutuba/ha in combination with 625 kg NPK/ha, 625 kg NPK/ha, and just Rutuba had the maximum agronomic efficiency of potassium (AEK). There were no significant variations in AEK between the application rates of single Rutuba, 625 kg NPK/ha and 937.5 kg NPK/ha, which was not significantly different from 1875 kg NPK/ha. The AEK ranged from 12.88 kg (1,875 kg NPK/ha) to 51.51 kg (625 kg Rutuba/ha + 625 kg NPK/ha). 937.5 kg Rutuba/ha and 625 kg Rutuba/ha+ 625 kg NPK/ha exhibited significantly greater agronomic phosphorus efficiency (AEP) than all other fertilizer regimes. In AEP, the application of 1875 kg Rutuba/ha, 625 kg Rutuba/ha, 625 kg NPK/ha, and 625 kg Rutuba/ha+ 625 kg NPK/ha did not differ significantly. The AEP for 1875 kg NPK/ha was not statistically different from the AEP for 937.5 kg NPK/ha, which was not substantially different from the AEP for 625 kg NPK/ha, 1875 kg Rutuba/ha, and 625 kg Rutuba/ha. The AEP varied between 12.88 (1,875 kg NPK/ha) and 61.58 (937.5% Rutuba/ha).

Table 9. Effects of varying inorganic and organic fertilizer regimes on the apparent nutrient recovery and the partial factor productivity of nitrogen, potassium, and phosphorus in clonal tea at Kianjokoma from June 2014 to June 2015.

Treatment	**ANR_N**	**ANR_K**	**ANR_p**	**PfP_N**	**PfP_K**	**PfP_P**
1,875 kg NPK/ha	0.11^{d}	0.32^{d}	0.05^{e}	4.38^{c}	22.80^{d}	22.80^{c}
625 kg Rutuba/ha+ 625 kg NPK/ha	0.64^{bc}	2.77^{abc}	0.31^{bc}	16.69^{c}	75.43^{bc}	78.31^{b}
937.5 kg NPK/ha	0.26^{d}	0.74^{cd}	0.12^{de}	8.76^{c}	45.53^{c}	45.53^{bc}
625 kg NPK/ha	0.41^{c}	$1.08b^{cd}$	0.19^{cd}	12.88^{c}	66.96^{bcd}	66.96^{b}
1,875 kg Rutuba/ha	0.84^{b}	4.01^{a}	0.32^{b}	41.66^{b}	101.07^{b}	88.37^{b}
937.5 kg Rutuba/ha	1.69^{a}	3.41^{a}	0.52^{a}	76.26^{a}	102.34^{b}	161.78^{a}
625 kg Rutuba/ha	1.35^{a}	2.96^{ab}	0.46^{a}	92.04^{a}	158.39^{a}	195.18^{a}
P-Value	<.001	0.01	<.001	<.001	0.003	<.001
LSD $p\leq 0.05$	0.33	2.09	0.13	21.52	52.3	43.87
CV%	27.2	31.1	26.2	33.5	21.2	26.2

Note:
Treatments with different letters in the same column are significantly different according to the least significant difference at $p\leq 0.05$; ANR_N: Apparent nutrient recovery of nitrogen; P_fP_N: Partial factor productivity of nitrogen ANR_K: Apparent nutrient recovery of potassium; PfP_K: Partial factor productivity of potassium; ANR_P: Apparent nutrient recovery of phosphorus; P_fP_P: Partial factor productivity of phosphorus. CV: coefficient of variation; LSD: least significant difference

Table 10. Effects of varying inorganic and organic fertilizer regimes on the agronomic efficiencies of nitrogen, potassium, and phosphorus in clonal tea at Kianjokoma from June 2014 to June 2015

Treatment	AE_N	AE_K	AE_P
1,875 kg NPK/ha	2.48^{d}	12.88^{c}	12.88^{d}
625 kg Rutuba/ha+ 625 kg NPK/ha	11.04^{cd}	51.51^{a}	53.46^{ab}
937.5 kg NPK/ha	4.94^{d}	25.70^{bc}	25.7^{cd}
625 kg NPK/ha	7.15^{d}	37.20^{ab}	37.2^{bc}
1,875 kg Rutuba/ha	18.04^{bc}	43.90^{ab}	38.27^{bc}
937.5 kg Rutuba/ha	29.03^{a}	37.55^{ab}	61.58^{a}
625 kg Rutuba/ha	21.17^{ab}	36.42^{ab}	44.89^{abc}
P-Value	<.001	0.04	0.005
LSD ≤0.05	9.51	21.72	21.03
CV%	39.7	15.5	30.2

Note: Treatments with different letters in the same column are significantly different according to LSD at p≤ 0.05; CV: coefficient of variation; AE_N: Agronomic efficiency of nitrogen; AE_K: Agronomic efficiency of potassium; AE_P: Agronomic efficiency of phosphorus

Effects on the cost of production and profitability in tea production

There was a significant (p≤0.05) impact on the estimated total production costs and estimated total income from the fertilizer application regimes (Table 11). The cost of applying 625 kg Rutuba + 625 kg NPK/ha was much higher than that of applying 1,875 kg Rutuba/ha. The projected total cost of application of 1,875 kg NPK/ha was significantly higher than the estimated total cost of application of other sole NPK rates, 937.5 kg Rutuba/ha and 625 kg Rutuba/ha, but was not significantly different from the anticipated total cost of application of 1875 kg Rutuba/ha. The projected total cost of application of 625 kg NPK/ha was significantly higher than that of 625 kg Rutuba/ha, but was not significantly different from that of 937.5 kg Rutuba/ha. The projected total cost per hectare varied between Ksh. 41,333 (control) to Ksh. 196, 557 (625 kg Rutuba + 625 kg NPK). The farmers' approach (625 kg NPK/ha) resulted in a total cost savings of 61.45 % compared to the application of 625 kg Rutuba/ha + 625 kg NPK/ha. Applying 625 kg Rutuba/ha combined with 625 kg NPK/ha generated significantly more predicted total revenue than any other fertilizer regime. It generated 40% and 215% more revenue than farmers' practices and the no-fertilizer control, respectively. Although the total expected revenue from the sole NPK fertilizer application regimes was not significantly different, it was much greater than the total estimated revenue from all the sole Rutuba application rates. Although the expected total revenue from the application of 1875 kg rutuba/ha was not significantly different from the estimated total revenue from the application of 937.5 kg rutuba/ha, both regimes generated significantly more revenue than the application of 625 kg rutuba/ha. The no–fertilizer control group generated much less revenue than the other treatments. Total income estimates ranged from Ksh. 144, 871 (no-fertilizer control) to Ksh. 456, 748 (625 kg NPK/ha+ 625 kg Rutuba/ha).

The application regimes for fertilizer had a substantial effect on the net returns. 625 kg Rutuba + 625 kg NPK/ha generated significantly more net revenue than all other treatments (Table 11), but 1,875 kg Rutuba/ha generated significantly less net revenue. However, there was no statistically significant difference in predicted net revenue between 937.5 kg NPK/ha and 625 kg NPK/ha. Those applications generated significantly more revenue than 1,875 kg NPK/ha, than all the sole Rutuba and the no-fertilizer control. The estimated net return on 1,875 kg NPK/ha was substantially greater than the anticipated net return on all other Rutuba rates and the no-fertilizer control. The net return was not substantially different between application regimes of 937.5 kg Rutuba/ha, 625 kg Rutuba/ha, and no-fertilizer control. Net revenue was anticipated to range between Ksh. 68, 256 (1,875 kg Rutuba/ha) to Ksh. 260, 191 (625 kg Rutuba/ha + 625 kg NPK/ha). 625 kg Rutuba + 625 kg NPK application yielded 27.4 % and 151.3 % more than farmers' practice and no-fertilizer control, respectively. Fertilizer rates increased from 625 kg NPK/ha (farmers' practice) to 937.5 kg NPK/ha and 1875 kg NPK/ha, respectively, reducing net returns by 4.7 % and 25.7 %.

Table 11. Cost of each fertilizer regime and the net revenue at Kianjokoma from June 2014 to June 2015

Fertilizer regime	CoF (Ksh/ha)	CoP (Ksh/ha)	CoAF (Ksh/ha)	TC (Ksh/ha)	TR (Ksh/ha)	NR (Ksh/ha)
1875 kg NPK/ha	84356	95008^{b}	1875	181239b	333003^{b}	151764^{c}
625 kg Rutuba/ha+ 625 kg NPK/ha						
625 kg NPK/ha	65619	130313^{a}	625	196557^{a}	456748^{a}	260191^{a}
937.5 kg NPK/ha	42178	94865^{b}	937.5	137980^{c}	332500^{b}	194520^{b}
625 kg NPK/ha	28119	92999^{b}	625	121743^{d}	325961^{b}	204218^{b}
1875 kg Rutuba/ha	112500	72906^{c}	1875	187281^{ab}	255537^{c}	68256^{e}
937.5 kg Rutuba/ha	56250	66735^{c}	937.5	123923^{d}	233907^{c}	109984^{d}
625 kg Rutuba/ha	37500	53675^{d}	625	91800^{e}	188132^{d}	96331^{d}
Control	_	41333^{e}	_	41333^{f}	144871^{e}	103539^{d}
p-value		<.001		<.001	<.001	<.001
LSD p≤ 0.05		10358		10358	36305	25947
CV%		7.3		4.4	7.3	10

Note: CoF-Cost of fertilizer; Cop-Cost of plucking; CoAF-Cost of applying fertilizer; NR-Net revenue; TC-Total cost; TR-Total revenue

Discussion

Using organic Rutuba resulted in a higher soil pH than all NPK fertilizer rates. Chong et al. reported similar findings (2008). The recent findings may be explained by the high pH of organic Rutuba (pH= 8.2). Thus, the addition of organic Rutuba to a generally acidic tea crop has the ability to raise the pH. When compared to NPK fertilizer rates and the no-fertilizer control, the application of organic Rutuba increased total carbon. That means continued use of organic Rutuba fertilizer increases total organic carbon, increasing soil fertility. In addition, using Rutuba fertilizer raised Mn, Cu, Fe, and zinc soil concentrations. That could be because the Rutuba fertilizer contains a higher concentration of Mn, Cu, Fe, and Zn than the NPK (26.5.5) fertilizer. The elevated pH caused by Rutuba fertilizer may also have increased nutrient availability. Nath (2013b) showed that the pH of the soil was positively connected with the micronutrients Mn, Fe, Cu, and Zn in a study on the status of micronutrients in tea plantations. That means continued use of Rutuba fertilizer will improve the soil's micronutrient condition, resulting in increased tea yield and quality (Sedaghathoor et al. 2009).

Because of leaching, denitrification, and plant uptake of nitrogen (Chong et al. 2008), as well as the low levels of nitrogen in the organic fertilizer, there was no significant difference in total nitrogen content between the Rutuba and NPK fertilizer regimes. Chong et al. reported similar findings (2008). The NPK fertilizer regimes produced soils with a greater P content than all Rutuba rates and no-fertilizer control. Generally, the P content of the soil increased as the NPK and Rutuba fertilizers rate increased. That could be explained by the poor mobility of phosphorus in the soil and the increase in P concentration as Rutuba and NPK fertilizer rates are increased. Nath (2013b) and Kekana et al. (2012) reported similar results, in which soil P increased as fertilizer rates increased. Compared to NPK fertilizer regimes and no-fertilizer controls, the organic Rutuba treatments enhanced soil Ca and Mg content. That could be attributable to the increased Ca and Mg concentrations in organic Rutuba, which were 3.1 percent and 0.4 percent, respectively, compared to NPK fertilizer. That means farmers' continued use of Rutuba fertilizer has the ability to raise the calcium and magnesium content of soils, whereas repeated use of NPK fertilizer alone results in soil depletion of calcium and magnesium. The fertilizer application boosted the second leaf's breadth and length. Chong et al. reported similar findings (2008). Increased NPK fertilizer rates from 625 to 1875 kg NPK/ha had no discernible effect on the average breadth and length of the second leaf. That indicates that 625 kg NPK/ha contained an acceptable amount of nitrogen, phosphorus, and potassium for leaf development. Sole Rutuba rates did not significantly increase the average length of the second leaf compared to the no-fertilizer control in the first season. Still, they increased it significantly in the second season. That could be explained by the fact that organic fertilizers take longer to release nutrients; nutrients were likely more readily available to the plant in the second season (Hazra 2016). Fertilizer use increased green leaf yields and made tea yields considerably. Applying 625 kg Rutuba/ha + 625 kg NPK/ha yielded the highest green leaf and black made tea yields. Because the organic fertilizer increased the availability of nutrients, the integrated system had the highest yield. Tabu et al. (2015) discovered that supplementing cattle manure with inorganic fertilizer increased tea yield.

When the Rutuba fertilizer rate was increased from 625 kg Rutuba/ha to 1,875 kg Rutuba/ha, the yields of made tea and green leaf rose, and to improve tea yields, larger Rutuba rates may be required. When NPK fertilizer rates increased from 625 kg NPK/ha to 1875 kg NPK/ha, there were no significant ($p \leq 0.05$) increases in green leaf and made tea yields. That could be because the tea plants received enough N, P, and K by applying 625 kg NPK/ha. When it comes to nitrogen, Hamid et al. (2002) found that applying more than 225 kg N/ha did not improve tea yield appreciably. 937.5 kg NPK/ha and 1875 kg NPK/ha provided 243.75 kg N/ha and 487.5 kg N/ha, respectively, in the current study, both of which were more than 225 kg N/ha. Compared to plots with NPK fertilizers, green leaf and made tea yields were lower in sole Rutuba plots. The low levels of mineralizable N in Rutuba could be attributable to this.

The leaf nitrogen content did not considerably increase as NPK fertilizer rates rose from 625 kg NPK/ha to 1875 kg NPK/ha. That may be due to inorganic nitrogen leaching and denitrification, which means that using higher NPK rates than 625 kg NPK/ha would result in N loss because the plant will not consume it. The leaf nitrogen content rose as the Rutuba fertilizer was raised from 625 kg Rutuba/ha to 1875 kg Rutuba/ha, showing that organic Rutuba may not be lost as quickly as inorganic NPK fertilizer by leaching. Compared to the other fertilizer rates, the application of 625 kg Rutuba/ha with 625 kg NPK/ha resulted in the greatest leaf nitrogen content, showing that the NPK and Rutuba improved N uptake. According to Tabu et al. (2015), increasing NPKS with organic manure resulted in higher leaf N content. The N leaf content of sole Rutuba was lower than that of sole NPK fertilizer, probably because of the low N content of Rutuba fertilizer. Increases in NPK fertilizer rates from 625 to 1,875 kg NPK/ha showed no influence on potassium leaf content, although increases in Rutuba fertilizer rates did. Micronutrient availability may have increased as a result. Applying 625 kg Rutuba/ha + 625 kg NPK/ha rates resulted in higher leaf phosphorus content than NPK fertilizer rates or the no-fertilizer control. That could be because the Rutuba fertilizer's organic P was less fixed in the soil, making it more available to the plant because of the higher pH. (Sultana et al., 2014), organic Rutuba fertilizer can be used as a phosphorus source for long-term tea cultivation. Rutuba rates were increased from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha, which increased the apparent nutrient recovery (ANR) of N, K, and P. However, increasing Rutuba rates to 1875 kg Rutuba/ha decreased the ANR_N and ANR_P while increasing the ANR_K, which suggests that Rutuba, when used in moderation, improves the apparent nutritional recovery of N, K, and P. The ANR_N, ANR_K, and

ANR_P all reduced when NPK fertilizer application rates were increased from 625 kg NPK/ha to 937.5 kg NPK/ha. That shows low levels of NPK contribute to the recovery of N, P, and K.

The partial factor productivity (PfP) of N, K, and P decreased when rates were increased from 625 kg/ha to 1,875 kg/ha for both NPK and organic Rutuba fertilizers. With an increase in potassium from 40 K20/ha to 80 K20/ha, Calvin et al. (2013) found that increasing nitrogen rates from 100 kg N/ha to 200 kg N/ha lowered the partial factor productivity of nitrogen (PfP_N) and partial factor productivity of potassium (PfP_K). NPK fertilizer nitrogen rates increased from 162.5 kg N/ha (625 kg NPK/ha) to 487.5 kg N/ha (1,875 kg NPK/ha) in the current study, while Rutuba fertilizer nitrogen rates grew from 13.13 kg N/ha (625 kg Rutuba/ha) to 39.38 kg N/ha (1,875 kg Rutuba/ha).

According to Jagadeeswaran et al. (2005), the partial factor productivity of NPK decreased as NPK levels increased. Increased Rutuba levels from 625 kg to 937.5 kg Rutuba/ha raised the agronomic efficiency of nitrogen (AEN). Still, additional increases to 1,875 kg Rutuba/ha decreased AEN, and increased NPK fertilizer from 625 kg to 1,875 kg NPK/ha decreased AEN. Increased the agronomic efficiency of potassium (AEK) on increased Rutuba fertilizer rates from 625 kg Rutuba/ha to 1,875 kg Rutuba/ha, meanwhile the AEK was reduced by increasing NPK fertilizer rates from 625 kg NPK/ha to 1875 kg NPK/ha. According to Calvin et al. (2013), raising potassium rates from 40 kg/ha to 80 kg/ha raised the AEK from -0.59 to 0.04. Increased Rutuba fertilizer rates from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha improved AEP, while increases to 1,875 kg Rutuba/ha resulted in AEp reduction; meanwhile increase in NPK fertilizer rates from 625 kg NPK/ha to 1,875 kg NPK/ha decreased AEP. That means using moderate amounts of Rutuba fertilizer improves N, P, and K efficiency, lowering pollution consequences. On the other hand, higher NPK fertilizer rates lower N, P, and K efficiency, potentially resulting in pollution in tea crops in the long term.

Compared to farmers' practices and other fertilizer regimes, the application of 625 kg Rutuba/ha + 625 kg NPK/ha yielded the highest net yields. That means farmers in Kianjokoma (the experimental location) should employ this fertilizer regime instead of the current one. Furthermore, as compared to the farmers' practice, this fertilizer regime has the potential to improve soil fertility. However, the net yields from the application of 625 kg Rutuba/ha and 937.5 kg Rutuba/ha were not significantly greater than the no-fertilizer control.

In summary, compared to the no-fertilizer control and NPK fertilizer, the study found that organic Rutuba increases soil pH, total organic carbon, Mn, Cu, Fe, Zn, Ca, and Mg. Soil pH was lowered after a sole application of NPK (26.5.5). Compared to sole NPK treatment rates, co-application of 625 kg Rutuba/ha and 625 kg NPK/ha increased soil pH, Cu, Fe, Zn, and Mg concentrations. Increases in NPK fertilizer rates from 625 to 1,875 kg NPK/ha did not affect leaf growth or yield. While compared to sole Rutuba and NPK, the application of 625 kg Rutuba/ha + 625 kg NPK/ha resulted in significantly higher cumulative green leaf and made tea yields. The leaf N concentration of Rutuba fertilizer was lower than that of NPK fertilizer, but the leaf P content was higher. Compared to Rutuba fertilizer rates, NPK fertilizer rates resulted in low K leaf content.

The ANRN increased when Rutuba fertilizer rates climbed from 625 kg Rutuba/ha to 937.5 kg Rutuba/ha, but decreased as Rutuba rates increased further. While compared to sole NPK fertilizer rates, the application of 625 kg Rutuba/ha + 625 kg NPK/ha improved N, P, and K utilization efficiency. On the other hand, the sole rutuba application rates had greater nutrient usage efficiencies of N, P, and K than the sole NPK fertilizer application rates. Therefore, the farmers' approach of applying 625 kg Rutuba/ha and 625 kg NPK/ha resulted in greater net returns.

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