

Full Length Research Paper

The influence of fertilizer type and application rates in tea cultivation on nitrogen and potassium efficiencies

Kibet Sitienei^{1,2*}, P. G. Home², D. M. Kamau¹ and J. K. Wanyoko¹

¹Tea Research Foundation of Kenya, Kericho, Kenya.

²Biomechanical and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.

Accepted 25 March, 2013

As the most important cultural practices for tea production, single effects of nitrogen (N) and potassium (K) fertilization on yield are well documented but their interactions and impact on their use efficiencies are poorly understood. It was necessary therefore to assess interactions and impact on their use efficiencies in tea cultivation as influenced by fertilizer application rates. This objective led to a comprehensive field investigation in strongly acidic soil tea plots at Tea Research Foundation of Kenya, Kangaita substation in Kerugoya using clone TRFK 11-4 in a 3x3, NxK RCB design. Treatments were nitrogen (0, 100 and 200 Kg N ha⁻¹) as urea and potassium (0, 40 and 80 Kg K₂O ha⁻¹) as muriate of potash (MoP) replicated thrice. A uniform single dose of phosphorus (40 Kg P₂O₅ ha⁻¹) was applied. Tea yield, plant biomass and plant nutrient concentrations were measured for calculation of plant nutrient uptake and efficiencies. Increased nitrogen rates from 100 to 200 Kg N ha⁻¹ increased agronomic efficiency of nitrogen from 0.33, 0.93 and 0.33 to 1.32, 1.08 and 0.37 at respective rates of potassium. Increased nitrogen rates from 0 to 200 Kg N ha⁻¹ increased agronomic efficiency of potassium from -0.59 and 0.04 to 6.67 and 1.26 at respective rates of potassium.

Key words: *Camellia sinensis* (L.), interactions, clones, concentration, nutrient removals.

INTRODUCTION

In recent years, sustainable agriculture has become a concern due to the pressures of the increasing nitrogen fertilizer costs and increased focus on environmental protection. Too often, problems associated with N in the environment are dismissed as primarily resulting from agricultural production systems and inefficiencies in properly managing N source and their use. Numerous efforts continue to improve N-use efficiency, minimize losses and leakage of N into important water bodies, prevent natural resources degradation, and to understand the environmental impacts of N. There is therefore greater attention to the efficient use of nitrogenous fertilizers (Rochester et al., 2007). The need to optimize

fertilizer inputs to meet crop requirements have also increasingly been identified as priorities for research in feedback from tea stakeholders.

Nitrogen and potassium are the major nutrients of tea plant without which it would not be feasible to achieve the commercial levels of production (Venkatesan et al., 2004). Nitrogen plays an important role in increasing the agricultural production and as a constituent of protein, it increases the tea value. Following application, nitrogen undergoes a series of transformation: hydrolysis, volatilization, nitrification, denitrification and mineralization. The processes of volatilization and denitrification lead to the loss of nitrogen in gaseous form, while

*Corresponding author. E-mail: sitnei@yahoo.com. Tel: +254723847454. Fax: +254 52 20575.

nitrification converts the ammoniacal nitrogen to nitrate form which is highly susceptible to leaching along with the percolating water. Leaching is often the most important process of nitrogen loss from the field soils. An estimated 25 to 50% of applied nitrogen is lost by leaching. Studies in other countries have suggested that nitrogen fertilizer can be used at a moderately lower rate and more efficiently than they have been traditionally used. However, the optimum nitrogen rates and nitrogen use efficiency are affected by a number of factors like yield potential, soil fertility and field management (Boquet, 2005; Clawson et al., 2008; Hou et al., 2007; Janat, 2008; Kumbhar et al., 2008).

Potassium is the most important cation not only in regard to its content in plant tissues but also with respect to its physiological and biochemical functions (Mengel et al., 1987). As an enzyme activator, potassium has been implicated in over 60 enzymatic reactions, which are involved in many processes in the tea plant such as photosynthesis, respiration, carbohydrate metabolism, translocation and protein synthesis (Dong et al., 2004; Pettigrew, 2008).

As many of these variables are fixed in tea production, nutritional management is likely to be one of the major factors that can be manipulated by the grower to influence yields. Over the last several years, increasing demand for Kenyan tea and increasing cost pressures have led growers to seek out better production techniques which would increase yields and reduce their costs of production. Such techniques include best management practices (BMP) for fertilizer application. Fertilizer costs can represent 20 to 25% of the total production costs and therefore its efficient use is critical.

Recent literature on improving nutrient use efficiency in crop-production systems has emphasized the need for greater synchrony between crop nutrient demand and their supply from all sources throughout the growing season (Cassman et al., 1993). This approach explicitly recognizes the need to efficiently utilize both indigenous and applied nutrient and is justified by the fact that losses from all nutrient-loss mechanisms increase in proportion to the amount of available nutrient present in the soil profile at any given time. Increased yields also can contribute to greater nutrients use efficiency from both indigenous and applied nutrient sources because fast growing plants have root systems that more effectively exploit available soil resources (Burns, 1980).

Crop health, insect and weed management, moisture and temperature regimes, supplies of nutrients, and use of the best adapted cultivar or hybrid, all contribute to more efficient uptake of available and greater conversion of plant nutrient to shoot yield. Assuming a well-managed crop, nitrogen recovery efficiency and profit from applied nutrient are therefore optimized with the least possible nutrient losses when the plant-available nutrient pool is maintained at the minimum size required to meet crop-nutrient requirements at each stage of growth. Too little nutrient reduces yields and profit while too much nutrient

is vulnerable to losses for example, is vulnerable to losses for example, N from leaching, volatilization, and denitrification.

The degree of synchrony between nutrient supply and demand and its influence on nitrogen recovery efficiency can be evaluated quantitatively when nutrient demand and supply can be measured. For example, yield level provided an estimate of crop nutrient demand and the indigenous nutrient supply was estimated by nutrient uptake in plots that did not receive applied nutrient.

Efficiency of nitrogen and potassium fertilizer application is affected by various factors (including soil type, soil original nitrogen and potassium supplying capacity, crop varieties, organic matter and the levels of other nutrient elements) (Timsina et al., 2001; Oborn et al., 2005), which in turn shape the dynamic equilibrium existing among the various forms of soil N and K (Zeng et al., 2000). Knowledge of this dynamic relationship is critical for the efficient management of nitrogen and potassium in agro-ecosystems.

MATERIALS AND METHODS

Research site and cultivar

This research was conducted at Tea Research Foundation of Kenya, Kangaita substation in Kerugoya. Kangaita (37° E, 17.8° S; 0°, 19.8° S; 2,130 m above sea level) is located on the slopes of Mount Kenya. The soils in the study site are reasonably uniform, have characteristic red clay humic loam, and are strongly acidic. These soils are classified as Acrisols. The field was planted with tea clone TRFK 11/4 at rectangular spacing of 1.22 m by 0.61 m (4 by 2 ft). Field site was selected based on fertilizers types that is, urea (46% N) and muriate of potash (60% K).

Experimental design

A randomized complete block design with three replications was used for the study. The treatments were nitrogen rates (0, 100 and 200 Kg N ha⁻¹year⁻¹.) and potassium rates (0, 40 and 80 Kg K₂O ha⁻¹year⁻¹). Nitrogen rates were arranged in blocks while potassium rates were completely randomized in the blocks. The sources of N and K were urea (46% N) and muriate of potash (60% K) respectively. Phosphorus was applied as a uniform single dose of 40 Kg P₂O₅ ha⁻¹year⁻¹.

Plant samples were collected in April of 2011, while yield data were recorded monthly. Plant densities were similar in all plots that is, each plot consisted of 150 bushes while the sub-plot consisted of 50 bushes. Plucking of tea was done in conformity with standard practice, where two leaves and a bud were removed every ten to fourteen days and yield data were recorded monthly.

Micro-meteorological variations

The local climate is humid subtropical with annual rainfall which ranges between 1700 to 2150 mm while temperature ranges between 14.5 to 17.8°C. Long rains start in mid-March while short rains start in mid-October. A summary of the major values of micro-meteorological parameters during the experimental periods is shown in Table 1.

Plant tissue collection

In each plot, tissues samples were collected separately for two leaves and a bud, third leaves, mature leaves and maintenance leaves. Tea plant was sampled from each plot and partitioned into two leaves and a bud, third, mature, maintenance leaves; green, brown branches; stems; and hairy, other roots. The wet, dry weight; nitrogen, and potassium concentrations of these plant parts were determined using standard procedures. Concentrations of nitrogen and potassium were expressed on a dry weight basis and the nutrient uptake and accumulation were calculated as the product of concentration and dry weight.

Plots yield data (buds and young leaves) were obtained monthly for a period of one year. The plot wise monthly yield data were converted into made tea per hectare, using Equation 1.

$$\text{Made tea yield} = \frac{\text{Green leaf weight} - \text{No. of bushes per hectare} \times 0.225}{\text{No. of bushes per plot}} \quad (1)$$

The figure 0.225 is green to made tea conversion factor.

Nitrogen and potassium use efficiencies

Evaluation of nitrogen and potassium used efficiencies are useful in determining the ability of tea plant to absorb and utilize nutrients for maximum yields. The nitrogen and potassium use efficiencies are based on subtraction Equations (2) and (3).

Agronomic efficiency (AE) is expressed as the additional amount of economic yield per unit nutrient applied (Equation 2).

$$\text{AE} = \frac{\text{Yield in fertilized plot (kg ha}^{-1}) - \text{Yield in control plot (kg ha}^{-1})}{\text{Quantity of fertilizer nutrient applied (kg ha}^{-1})} = \text{kg ha}^{-1} \quad (2)$$

Apparent nutrient recovery efficiency (ANR) has been used to reflect plant ability to acquire applied nutrient from soil and is determined using equation 3.

$$\text{ANR} = \frac{\text{Nutrient uptake in fertilized plot (kg ha}^{-1}) - \text{Nutrient uptake in control plot (kg ha}^{-1})}{\text{Quantity of fertilizer nutrient applied (kg ha}^{-1})} = \text{kg ha}^{-1} \quad (3)$$

The partial factor productivity (Pfp) from applied nutrients this is a useful measure of nutrient use efficiency because it provides an integrative index that quantifies total economic output relative to utilization of all nutrient resources in the system (Cassman et al., 1996). It is the ratio of yield to applied nutrients as stated by Equation (4).

$$\text{Pfp} = \text{Yield of made tea in kg ha}^{-1} / \text{Amount of fertilizer nutrients applied in kg ha}^{-1} \quad (4)$$

Determination of nitrogen and potassium in tea plant samples

Chemical analysis of nitrogen in tea partitions

Total nitrogen concentration was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982). 0.1 g of milled samples was digested for an hour in concentrated H₂SO₄ plus a quarter catalyst tablet. After cooling, the digest was made alkaline with 40%

NaOH solution and the NO₃ distilled was collected in 10 ml boric acid containing mixed indicator. Total N was determined by titrating the distillate against 0.035 M HCl.

Chemical analysis of potassium in tea partitions

Exactly 0.25 g of the dried and ground tea leaf sample was ashed for four hours and then digested using 2 parts of 1:1 mixture of concentrated HNO₃ (69 to 70.5%) and concentrated HCl (37%) under reflux to 3 parts of hydrogen peroxide. Concentrations of K in the digests were then determined using flame Photometer (Spencer, 1950).

Statistical analysis

The data were subjected to the analysis of variance (ANOVA) using the MSTATC software package (Russel, 1995). In case of significant treatment effects, a comparison of means was performed by means of least significant difference (LSD) method at a significance level of 5% (p = 0.05) (Steel et al., 1997). Use of difference between treatments implies statistical difference (P = 0.05) while no difference implies no statistical difference. The mean tea yield, plant biomass and plant nutrient concentrations were then used for calculation of nitrogen and potassium efficiencies.

RESULTS AND DISCUSSION

Annual yield response to nitrogen and potassium fertilization

Processed (made) tea yield, recorded between September 2010 and August 2011 were analyzed and their means are as shown in Figure 1.

From Figure 1, nitrogen is shown to be the most important yield increasing fertilizer. This observation was consistent with that of Foth et al., (1996) who observed that nitrogen is the mineral nutrient most commonly deficient in agricultural soils.

The highest made tea yield (872 Kg ha⁻¹) was obtained with 200 kg N ha⁻¹ and 40 kg K ha⁻¹ while the lowest (755 Kg ha⁻¹) with 40 kg ha⁻¹ K without nitrogen. The increased made tea yield at the highest level of nitrogen was probably due to the availability of more nutrients, which helped, in maximum vegetative growth of tea plant.

The differences regarding made tea yield in all the treatments were non-significant. De Datta et al. (1985) showed that the effect of nitrogen on other crops significantly affected the response to potassium presence; when nitrogen fertilizers are not utilized, they do not react to potassium fertilizer. At stable nitrogen rate of 200 kg ha⁻¹ year⁻¹, there was significant reduction of made tea yield (100 Kg) among the different potassium levels (0 to 80 kg K ha⁻¹).

Considering the seasonal variation in tea growth as affected by weather conditions (Table 1), one dose of nitrogenous fertilizer at a fixed time may not match crop demand of clonal tea plants during the whole growing season. Thus, for optimizing the nitrogenous fertilizer

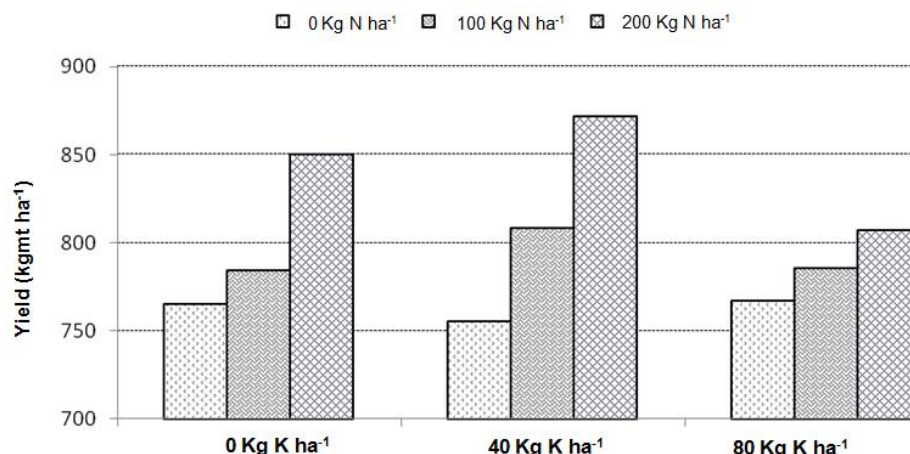


Figure 1. Mean tea yields per plot affected by nitrogen and potassium treatments.

Table 1. Monthly total rainfall, maximum, minimum and mean air temperature, soil temperature and relative humidity at Kangaita.

Month	Total rainfall (mm)	Max. Air Temp. (°C)	Min. Air Temp. (°C)	Mean Air Temp. (°C)	Soil Temp. (°C)	RH (%)
Sep	41.6	19.2	19.2	14.6	18.1	87
Oct	148.9	20.8	20.8	16.1	20.1	83
Nov	146.4	20.2	20.2	15.3	18.9	90
Dec	48.4	21.4	21.4	15.4	20.9	77
Jan	29.7	21.9	21.9	15.3	21.6	67
Feb	15.0	21.0	21.0	15.7	21.8	56
Mar	76.2	22.0	22.0	17.4	22.4	62
Apr	290.7	20.7	20.7	17.9	19.6	69
May	486.5	20.9	20.9	18.0	17.7	77
Jun	57.7	15.0	15.0	13.7	17.9	88
Jul	46.5	18.8	18.8	15.3	17.6	74
Aug	110.3	17.6	17.6	14.8	16.3	75
Mean	124.8	20.0	11.6	15.8	19.4	75.4

response, there is need to further explore the benefits of matching demand and supply taking into account not only productivity but also the risk on nitrogen losses. On the other hand, since fertilizers do not improve soil physical structure or enhance soil biological activity, they are, by themselves, usually insufficient to maintain soil fertility. Increased water availability, for example, improves the utilization of fertilizer by crops.

Plant biomass

Interaction effect of nitrogen and potassium on the dry weight of tea plant was not significant.

In this research, lack of significance yield response to fertilizer treatments (Figure 1) led to lack of significance difference in dry matter to fertilizer treatments (Table 2).

Concentrations of nitrogen and potassium in tea

Plant tissue analysis provided a mean of assessing the plant uptake, and removal from the soil, of N and K.

Nitrogen concentration in tea plant tissues

Nitrogen concentrations of two leaves and a bud, third, mature and maintenance leaves, green and brown branches, stem, hairy and other roots were determined and their results are given in Table 3.

Different nitrogen rates, potassium rates and their interactions had insignificant effect on two leaves and a bud, third leaves; green branches, brown branches, stem, hairy roots and other roots nitrogen nutrient concentrations (Table 3). They were almost similar within

Table 2. Mean effects of N-K fertilization on the dry weight of Tea plant.

Treatment	2 leaves + Bud	Other leaves	Green Branches	Brown Branches	Stem	Hairy Roots	Other roots
N ₀ K ₀	8.19	85.79	18.79	742.39	164.54	14.90	539.39
N ₀ K ₁	9.00	69.84	14.60	770.33	242.22	11.73	462.01
N ₀ K ₂	9.60	85.95	21.34	859.00	223.92	15.52	733.97
N ₁ K ₀	8.55	79.17	21.61	923.79	205.64	11.04	541.84
N ₁ K ₁	9.28	75.77	22.01	1006.78	222.07	12.59	522.52
N ₁ K ₂	8.41	59.46	17.79	813.92	170.67	11.83	391.46
N ₂ K ₀	8.66	85.63	20.54	944.58	182.59	14.16	544.73
N ₂ K ₁	8.21	56.71	14.08	715.95	149.53	10.85	357.45
N ₂ K ₂	10.56	57.81	20.61	777.87	193.27	12.34	409.23
CV (%)	16.60	26.12	26.33	22.63	28.45	22.49	30.44
P(0.05)	ns	ns	ns	ns	ns	ns	ns

(N₀=0; N₁= 100; N₂= 200) kg N/ha; (K₀=0; K₁=40; K₂=80) kg K₂O/ha, CV = Coefficient of variation, ns = not significant.

Table 3. Effect of N and K interaction on plant partitions nutrient N (%).

Treatment	2 leaves +Bud	3 rd leaves	Mature leaves	Maintenance leaves	Green Branches	Brown Branches	Stem	Hairy Roots	Other roots
N ₀ K ₀	4.49	3.25	2.59 ^{ab}	2.92 ^{abc}	2.30	0.58	0.31	1.59	0.30
N ₀ K ₁	4.49	3.09	2.77 ^a	2.64 ^{cd}	1.55	0.45	0.33	1.68	0.29
N ₀ K ₂	4.86	3.38	2.33 ^{bc}	2.37 ^{de}	1.83	0.40	0.38	1.57	0.31
N ₁ K ₀	4.80	3.35	2.52 ^{ab}	2.82 ^{abc}	1.95	0.53	0.39	1.71	0.39
N ₁ K ₁	4.78	3.54	2.11 ^c	2.34 ^e	1.83	0.52	0.39	1.70	0.34
N ₁ K ₂	4.54	3.18	2.12 ^c	2.44 ^{de}	2.04	0.55	0.34	1.76	0.30
N ₂ K ₀	4.69	3.50	2.72 ^a	3.09 ^a	2.28	0.55	0.45	1.84	0.49
N ₂ K ₁	4.78	3.62	2.74 ^a	2.97 ^{ab}	2.03	0.60	0.36	1.39	0.45
N ₂ K ₂	4.79	3.38	2.72 ^a	2.80 ^{bc}	1.94	0.46	0.35	1.51	0.39
CV (%)	9.10	7.76	12.26	10.92	21.41	12.65	17.99	13.47	26.11
LSD (5%)	ns	ns	0.218	0.209	ns	ns	ns	ns	ns

(N₀=0; N₁= 100; N₂= 200) kg N/ha; (K₀=0; K₁=40; K₂=80) kg K₂O/ha, CV = Coefficient of variation, ns = not significant, *each row with same letters was not significantly different (p< 0.05).

all ratios. Increased nitrogen rates had significantly varied nitrogen nutrient concentrations in mature and maintenance leaves. Increased potassium rates significantly reduced nitrogen nutrient concentrations in maintenance leaves from 2.95 to 2.54%.

From the table, it is clear that nitrogen content were high in young leaves than old ones. This reflects the fact that nitrogen is highly mobile and is often translocated from old leaves to young leaves (Marschner, 1995). It has been reported for other crops, that plants allocate nitrogen to the youngest leaves in order to maintain a high-rate of canopy photosynthesis (Hirose et al., 1987; Lemaire et al., 1997). Indeed, the nitrogen content of 'two leaves and a bud' is less sensitive to nitrogen fertilization; hence, the use of the mature leaf for the diagnosis of the nutrient status of tea bushes is recommended in East Africa (Othieno, 1988). Cultivated tea is maintained as a low bush in a continuous vegetative phase with regular

removal of the young shoots. For annual crops, nitrogen uptake is regulated by the crop dry mass accumulation under non-limiting nitrogen supply within species and across environments (Lemaire et al., 2007).

Potassium concentration in tea plant tissues

Potassium concentrations of two leaves and a bud, third, mature and maintenance leaves, green and brown branches, stem, hairy and other roots were determined and their results are given in Table 4.

There was significant variation in potassium concentrations among the different nitrogen rates, potassium rates and their interactions except two leaves and a bud, green branches and stems (Table 4). Increased nitrogen rates from 0 to 200 kg N/ha significantly reduced potassium nutrient concentrations

Table 4. Effect of N and K interaction on plant partitions nutrient K.

Treatment	2 leaves + Bud	3 rd leaves	Mature leaves	Maintenance leaves	Green Branches	Brown Branches	Stem	Hairy Roots	Other roots
N ₀ K ₀	2.77	2.58 ^{ab}	2.37 ^{ab}	2.77 ^a	1.93	0.72 ^a	0.50	1.05 ^{ab}	0.59 ^{cd}
N ₀ K ₁	2.33	3.18 ^{ab}	2.65 ^a	2.60 ^{ab}	2.18	0.58 ^{ab}	0.50	0.91 ^{ab}	0.66 ^c
N ₀ K ₂	3.01	3.20 ^{ab}	2.83 ^a	2.93 ^a	2.41	0.59 ^{ab}	0.58	1.24 ^{ab}	0.71 ^{bc}
N ₁ K ₀	2.37	2.77 ^{ab}	2.10 ^{ab}	2.59 ^{ab}	2.26	0.59 ^{ab}	0.50	1.29 ^a	0.63 ^{cd}
N ₁ K ₁	2.58	3.03 ^{ab}	2.65 ^a	2.72 ^a	2.42	0.72 ^a	0.66	1.04 ^{ab}	0.72 ^{bc}
N ₁ K ₂	2.52	3.27 ^a	2.46 ^{ab}	2.57 ^{ab}	2.57	0.74 ^a	0.72	0.89 ^{ab}	0.69 ^{bc}
N ₂ K ₀	2.31	2.40 ^b	1.72 ^b	2.16 ^b	2.05	0.42 ^b	0.47	0.61 ^b	0.52 ^d
N ₂ K ₁	2.77	3.14 ^{ab}	2.13 ^{ab}	2.74 ^a	2.43	0.66 ^a	0.66	1.05 ^{ab}	0.82 ^{ab}
N ₂ K ₂	2.58	3.26 ^a	2.46 ^{ab}	2.87 ^a	2.24	0.68 ^a	0.63	1.18 ^{ab}	0.88 ^a
CV	11.05	9.51	11.30	6.92	16.24	11.35	15.89	21.73	7.15
LSD (5%)									
N	ns	ns	0.19	ns	ns	0.05	ns	ns	0.04
K	ns	0.20	0.19	0.13	ns	0.05	0.07	ns	0.04
N*K	ns	ns	ns	0.23	ns	0.05	ns	0.27	0.06

(N₀=0; N₁= 100; N₂= 200) kg N/ha; (K₀=0; K₁=40; K₂=80) kg K₂O/ha, CV = Coefficient of variation, ns = not significant, *each row with same letters was not significantly different (p< 0.05).

Table 5. Nitrogen and potassium use Agronomic Efficiency (AE), Apparent Nutrient Recovery (ANR) and Partial factor productivity (Pfp)

Treatment	AE _N	AE _K	ANR _N	ANR _K	Pfp _N	Pfp _K
N ₀ K ₀						
N ₀ K ₁		-0.59		-0.15		43.17
N ₀ K ₂		0.04		-0.02		23.98
N ₁ K ₀	0.33		0.043		13.69	
N ₁ K ₁	0.93	3.05	0.037	0.06	14.11	46.21
N ₁ K ₂	0.33	0.59	-0.003	0.03	13.71	24.58
N ₂ K ₀	1.32		0.015		8.39	
N ₂ K ₁	1.08	6.67	0.019	0.15	8.06	49.84
N ₂ K ₂	0.37	1.26	-0.006	-0.01	7.46	25.24

(N₀=0; N₁= 100; N₂= 200) kg N/ha; (K₀=0; K₁=40; K₂=80) kg K₂O/ha

immature leaves from 2.6 to 2.1% had varied effect on brown branches and increased potassium nutrient concentrations in other roots from 0.65 to 0.74%. Generally, potassium content in third, mature and maintenance leaves in K₂ (80 Kg K ha⁻¹) treatments was more than K₁ (40 Kg K ha⁻¹) and K₀ (control) treatments as expected. Increased potassium rates from 0 to 80 kg K₂O/ha significantly increased potassium nutrient concentrations in third leaves from 2.6 to 3.2%, in mature leaves from 2.1 to 2.6%, in maintenance leaves from 2.5 to 2.8%, in brown branches from 0.58 to 0.67%, in stems from 0.49 to 0.64% and other roots from 0.58 to 0.76%.

The positive N-K interaction is also dependent on the form of nitrogen supplied. Nitrate uptake has been shown to stimulate net K⁺ uptake in various crop species, suggesting that the NO₃⁻ ion serves as a mobile accompanying anion during K⁺ uptake and/or transport

(Pettersson, 1984). It has been reported that NH₄⁺ reduces K⁺ uptake in plant roots (Scherer et al., 1984; Wang et al., 2003; Lu et al., 2005; Guo et al., 2007) because NH₄⁺ and K⁺ have similar charges and hydrated diameters (Wang et al., 1996).

Dang (2005) reported that plant nutrient concentrations in the tea plant are highest in the young leaves and buds with concentration ranges for the major nutrient element K of 2.3 to 3.0%. These ranges of values are highly consistent with the levels obtained in the leaves of the studied tea plants.

Moreover, these results indicated that the harvested tea, which involves mainly the young leaves and buds, represents a significant, permanent removal of potassium from the soil.

Potassium is highly mobile within plants but its flow and partitioning can change depending on the forms of nitrogen

supply. NH_4^+ nutrition in comparison to NO_3^- supply results in more K translocation to leaves.

Nitrogen and potassium use efficiencies by tea plant

Table 5 below shows calculated agronomic efficiency, apparent nutrient recovery and partial factor productivity.

Different nitrogen rates, potassium rates and their interactions had general effect on agronomic efficiency, apparent nutrient recovery and partial factor productivity. Increased nitrogen rates from 100 to 200 kg N/ha increased agronomic efficiency of nitrogen from 0.33, 0.93 and 0.33 to 1.32, 1.08 and 0.37 at respective rates of potassium. While increased potassium rates from 40 to 80 kg K_2O /ha had varied effect on 100 kg N/ha but reduced agronomic efficiency of nitrogen from 1.32 to 0.37 at 200 kg N/ha. The highest nitrogen and potassium agronomic efficiencies were obtained from the plots which received 200 kg N/ha at 0 and 40 K_2O respectively. Increased nitrogen rates from 0 to 200 kg N/ha increased agronomic efficiency of potassium from -0.59 and 0.04 to 6.67 and 1.26 at respective rates of potassium. While increased potassium rates from 0 to 80 kg K_2O /ha reduced agronomic efficiency of potassium except at 0 kg N/ha. The negative value indicates that immobilization (microbial and/or chemical) exceeded the mineralization, resulting in less net mineralization.

Increased nitrogen rates from 100 to 200 kg N/ha reduced estimated apparent nutrient recovery of nitrogen derived from the N uptake by harvested shoots and the fertilizer N applied from 0.043 and 0.037 to 0.015 and 0.019 at respective rates of potassium except at 80 kg K_2O /ha. Increased nitrogen rates from 0 to 200 kg N/ha increased apparent nutrient recovery of potassium from -0.15 and -0.02 to 0.06 and 0.03 at respective rates of potassium except at 200 kg N/ha and 80 kg K_2O /ha. While increased potassium rates from 0 to 80 kg K_2O /ha reduced apparent nutrient recovery of nitrogen and potassium. Regardless of treatment, the low percentages (Apparent Nutrient Recovery) of N indicate that the N nutrient recovery by tea clone TRFK 11-4 on Kangaita was low.

Increased nitrogen rates from 100 to 200 kg N/ha reduced partial factor productivity of nitrogen from 13.69, 14.11 and 13.71 to 8.39, 8.06 and 7.46 at respective rates of potassium. Increased nitrogen rates from 0 to 200 kg N/ha increased partial factor productivity of potassium from 43.17 and 23.98 to 49.84 and 25.24 at respective rates of potassium. While increased potassium rates from 0 to 80 kg K_2O /ha had varied effect on partial factor productivity at 100 kg N/ha but reduced the partial factor productivity for nitrogen at 200 kg N/ha and for potassium.

In many cases, ample amounts of fertilizer especially nitrogenous, which are more than the crop requires, are applied in the field. Even so, the amount of nitrogen absorbed by the plant may still be insufficient for the crop

to attain its yield potential, because of low efficiency of absorption. Low nutrient uptake and low apparent nutrient recovery efficiency in such cases is caused by the unfavorable condition of the plants or the soil, rather than by the nitrogen supply. The soil-plant system inefficiencies prevent complete utilization of the nitrogen, leaving residual in the soil, which is a waste of natural resources and cause for environmental concern. Because chemical fertilizers are used without regard for how they fit into the ecosystem, they are used inefficiently. Typically 25 to 50% of the applied compounds are likely to be taken up by the crop, even when efficiencies are high. Much of the extra is likely to end up as pollution. Thus, the inefficiency and pollution by chemical fertilizers results from the fact that these compounds fail to fit into soil nutrient recycling.

Ranganathan (1981a) showed that the efficiency of fertilizer applied K decreased with increasing yields probably because of limitation of transport processes within soil. At high yield levels especially during the peak growing seasons, the K demand is very high. The demand can possibly be met by increasing the K^+ concentration in the soil solution, thereby effectively facilitating the diffusion process (Ranganathan et al., 1985).

Low K use efficiency often happens as the result of soil K leaching losses, especially in the subtropical environment. At the presence of N, K leaching is decreased because that N increases K uptake by plants (Tung et al., 2009). When urea is applied to a soil, it is hydrolyzed to ammonium carbonate. In carbonate-bearing soil, the acid produced by nitrification of ammonium carbonate gives rise to an increase in concentration of Ca^{2+} and Mg^{2+} in the soil solution, which could exchange with other cations, including K^+ . Therefore, application of urea to agricultural soils leads to increase K^+ leaching (Kolahchi and Jalali, 2007). If the efficiency of N and K fertilizers in tea fields is increased, the environmental problems of soil acidification, water contamination, and N_2O emission in Kenya's tea-growing regions would be solved gradually.

Conclusion

Increased nitrogen rates increased agronomic efficiencies of nitrogen and potassium, apparent nutrient recovery of potassium and partial factor productivity of potassium but generally reduced estimated apparent nutrient recovery of nitrogen derived from the N uptake by harvested shoots and partial factor productivity of nitrogen at respective rates of potassium. Increased potassium rates reduced apparent nutrient recovery of nitrogen and potassium.

REFERENCES

Bremner JM, MulveneyCS (1982). Nitrogen total. In A. L. page (ed.),

- Methods of soil analysis. Agron. No.9, Part 2: Chemicals and Microbiological properties, 2nd ed., Am. Soc. Agron. Madison, WI, USA.p 595-624
- Burns IG (1980). Influence of the spatial distribution of nitrate on the uptake of N by plants: A review and a model for rooting depth. *J. Soil Sci.* 31:155-173.
- Cassman KG, Gines GC, Dizon MA, Samson MI, Alcantara JM, (1996). Nitrogen use efficiency in tropical low land rice systems: Contributions from indigenous and applied nitrogen. *Field Crop Res.* 47:1-12.
- Cassman KG, Kropff MJ, Gaunt J, Peng S, (1993). Nitrogen use efficiency of irrigated rice: What are the key constraints? *Plant Soil* 155/156:359-362.
- Dang MV, (2005). Soil-plant nutrient balance of tea crops in the northern mountainous region, Vietnam. *Agriculture, Ecosystems and Environment*, 105:413-418.
- Hirose T, Werger MJA, (1987). Maximizing daily canopy photosynthesis with respect to the leaf nitrogen allocation pattern in the canopy. *Oecologia* 72:520-526.
- Jaetzolt R, Schmidt H (1983). Farm management Handbook, East Kenya. Ministry of Agriculture, Kenya 2 (C):79-109.
- Lemaire G, Oosterom VE, Sheehy J, Jeuffroy MH, Massignan A, Rossato L (2007) Is crop N demand more closely related to dry matter accumulation or leaf area expansion during vegetative growth? *Field Crops Res.* 100:91-106.
- Lemaire G, Gastal F (1997) N uptake and distribution in plant canopies. In: Lemaire, G. (Ed.), *Diagnosis of the nitrogen status in crops.* Springer-Verlag, Berlin pp. 3-43.
- Marschner H (1995) *Mineral Nutrient of Higher Plants*, 2nd ed. Academic Press, London, pp. 106-130.
- Mengel K, Kirby EA (1987) *Principles of plant nutrition.* Bern, Switzerland: IPI Publication.
- Nand R (2000) Long-term Effects of Fertilizers Rice-Wheat-Cowpea Productivity and Soil Properties in a Mollisols. In: Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (eds I. P., Abrol, K. E. Bronson, J. M. Duxbury and R. K Gupta) pp. 50-55. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India
- Othieno CO, (1988) Summary of recommendations and observations from TRFK. *Tea* 9, 50-65.
- Ranganathan V (1981a) Recent advances in agronomic practices-technology for increasing efficiency of fertilizer use. *Bulletin of United Planters - Association of South India Tea Science Department* 37:92-103.
- Ranganathan V, Natesan S (1985) Nutrition of tea. In: *Proceedings of an International Symposium of Potassium in Agriculture held 7-10 July 1985 in Atlanta, Georgia.* Robert D. Munson (Ed.): ASA-CSSA-SSSA, Madison, Wisconsin USA 1985. pp. 981-1022.
- Ranganathan V, Natesan S, (1983) Manuring of tea—revised recommendations (1982). In: *Handbook of Tea Culture 1/1983*, UPASI, Tea Res. Inst. Cinchona, India p. 22.
- Russel F (1995). Mstat-C computer based statistical software package.
- Spencer AG (1950). Flame photometry. *Lancet.* Nov 25; 2(6639):623-627
- Steel RGD, Torrie JH, Dickey DA (1997). *Principles and Procedures of Statistics. A Biometrical Approach*, 3rd Ed. McGraw Hill Book Co. New York 172-177
- Tan, K. H., 1996: *Soil sampling preparation and analysis.* New York: Marcel Dekker.
- Venkatesan S, Murugesan S, Senthur Pandian VK, Ganapathy MNK, (2004). Impact of sources and doses of potassium on biochemical and Green leaf parameters of tea. P. 536