Prospects for organic tea farming in Kenya: Two case studies

Kamau, D.M.; Kekana,V. ; Sitienei, K.; Wanyoko, J.K. and Nyabundi, K.

Tea Research Foundation of Kenya. P.O. Box 820-20200, Kericho, Kenya.
Email: dmkamau@tearesearch.or.ke

ABSTRACT

Organic tea farming entails non-use of pesticides and inorganic fertilizers, including the processing and packaging of the tea. This implies that documents must be filed which prove all requirements are met throughout the growing, processing, packaging, and which can be traced by the organic certification organization. Today, almost all kinds of tea grown in Kenya are non-organic. This is despite the fact that only NPK fertilizers are used in tea farms. It is difficult just to make an organic tea farm because of the many non-organic tea farms around it. Dispersals of chemical fertilizers or herbicides and other chemical agents interfused through the soil from surrounding farms can enter the organic farm. Therefore, it is necessary to make a buffer zone or shelterbelt between an organic tea farm and non-organic tea farm or to embrace organic tea cultivation together with the neighbouring farmers. However, the starting point is to establish that organic tea can indeed be grown economically. Two long term studies comparing different sources of organic manures in Kericho and Kangaita were assessed for yield, some soil properties and tea quality chemical parameters. The results reveal that although the organic manures do not give as high yields as the enriched manure treatments from inorganic sources, rates of 120-150 kgN/ha would suffice to replenish the lost nutrients thus maintaining tea bush health and also optimal yields. The soil pH, available K and Ca results also demonstrated that the organic manures can maintain the acidity levels of the soils thus addressing the often controversial land sustainability problem arising from use of external inputs in tea agro-ecosystems. Organic manures and enriched manures increased the TF and TR content while caffeine increased with increase in nitrogen rates. This was more pronounced when using inorganic fertilizers and enriched manures. The study suggests that development and promotion of organic and low carbon in the Tea Industry is key to the attainment of ecological health and environment protection by both the tea producers and consumers. Tea growers have to be compensated by benefiting from premium organic tea prices due to the loss in yields as seen by the higher yields arising from the enriched manures.

INTRODUCTION

The term "organic" describes how an agricultural product is grown and processed. An organic product is free from chemicals, antibiotics, synthetic hormones, genetic modifications, and sewage sludge, and is minimally processed without artificial ingredients, preservatives, or irradiation in order to maintain the integrity of the food, preserve ecological harmony and promote biodiversity. It is therefore true to say that by consuming organic varieties of tea, we promote our health as well as our land and environment. It is generally acknowledged that an organic tea farm lives together in the ecosystem while a non-organic tea farm tries to control the ecosystem. The advancement of each approach of organic and modern cultivation is completely different, and each has known advantages. Organic farming maintains and replenishes soil fertility without the use of toxic pesticides and fertilizers, instead uses natural methods to control pests, weeds and disease. Nutrient re-cycling is thus crucial in organic tea farming as it reduces nutrient losses in tea fields.

Organic cultivation entails growing of agricultural crops the historic way before modern agriculture commenced. This implies that a certification often done by a third-party state or private certifying organization is essential to verify that a product strictly adheres to the organic standards. The third-party certifier thoroughly inspects the location where the organic product is produced and handled to ensure that all organic standards are established, followed and met. To grow organic tea and to have that tea certified officially creates a unique and pristine environment, which requires special efforts.

The following requirements must be met to be officially certified as organic: i) No chemical fertilizer or pesticides for at least three years. ii) Only use organic fertilizer with no genetic modification (that is, no GMOs). iii) The tea must be processed and packaged in separate facilities and lines only for organic tea. iv) Documents must be filed which prove all requirements are met throughout the growing, processing and packaging, and which can be traced. v) All documents, tea farms, processing facilities, and packaging locations are periodically inspected by the organic certification organization.

Organic tea has a simple and traditional flavour which is probably the same as tea grown many years ago in countries that have a long history of tea growing including the smallholder sub-sector in Kenya. Organic tea therefore directly brings the antecedents in the flavour than non-organic tea. The antecedents are the features of breed, soil, climate, and efforts by the farmer. Examples include; Japan, where the flavour of organic Japanese tea is affected by farmer's efforts, climate and soil. To grow high grade and quality organic tea, it is required to meet some terms, which are: i) extra time and effort, ii) the range of temperature between day and night in the rolling hills, and iii) calcareous earth. There are not so many places even in Japan which are perfect for farming high quality organic tea. When a lot of time and effort is put into the growing of organic tea, the tea flavour can be highly improved. Unfortunately, such excellent grade and quality organic tea is rare, because most organic farmers think that growing such high grade organic tea will not bring farmers economic success, but just require a lot of time and effort. Most tea farmers in Japan therefore grow low to middle grade organic tea. In Kenya, efforts to have quality determination, hence marketing through location of production, for instance Geographic Indicators, are in progress.

Organic fertilizer works slowly, chemical fertilizer in non-organic tea farms makes the growing process much easier. From the perspective of modern cultivation, it can be said that chemical fertilizers produced considerable improvement of traditional cultivation and brought the Tea Industry amazingly high productivity and is definitely one of the contributions of modern agriculture.

An organic tea farm generally has beneficial insects and bugs (for instance, earthworms, embryo of insects, ants, and beneficial bacteria), has soil that is softer and airy due to long term use of organic fertilizers, and it encourages full canopy cover to reduce on manual weeding. Complete documentation (record keeping) and an annual audit must be done for an organic tea farm that includes the following: i) purchasing organic fertilizer, ii) tea farm operation, which include fertilizing, weeding and harvesting, iii) production outputs and control of all of them; and iv) delivery management. To ensure compliance, an annual audit is practiced every year by an auditor of the organic certification body. All of the above documents are inspected to make sure they meet and exceed the organic certification requirements.

The organic materials commonly used especially by the smallholders, according to Lekasi (2003), include: i) Fresh, dried or composted livestock and poultry manure. ii) Crop residues that are recycled after a crop is harvested. iii) Green manure obtained either on or off the farm. iv) Biomass resulting from short and long-term fallows. v) Agro-industrial by-products such as coffee husks and sugarcane bagasse. vi) Forest litter, bark and wood shavings.

The nutrient concentration, therefore, serves as an indicator of the quality of manure. Some nutrient concentrations of some selected dry compostable materials are shown in Table 1.

Table 1: Common ranges of nutrient concentrations in different types of manures.

Type	N	P	K	Ca	Mg	C:N Ratio
Chicken manure	4.5	0.8	0.7	1.8	0.4	7
Cattle manure	1.5	0.5	0.6	1.0	0.3	18
Grass cuttings	1.2	1.1	2.0	<0.1	0.1	27
Alfafa	2.4	0.2	1.8	1.4	3.9	15
Maize stover	0.9	0.1	1.2	0.4	0.1	42
Wheat straw	0.6	0.1	1.2	0.4	0.1	90
Mixed green weeds	2.3	0.3	1.3	0.1	<0.1	21

Source: Lekasi *et al.*, 2001.

Today, the vast majority of tea is non-organic, also known as conventionally-grown. Only a small percentage (of less than 1% of all tea grown world-wide) is organic. It is difficult just to make an organic tea farm because there are so many non-organic tea farms around it. Dispersals of chemical fertilizer or pesticide and chemical agents interfused through the soil from surrounding farms can enter the organic farm. Therefore, it is necessary to make a buffer zone or shelterbelt between an organic tea farm and non-organic tea farm or to embrace organic tea cultivation together with the neighbouring farmers. It is important to note that not all organic products are the same as there are different categories of organic. For example, to display the United States Department of Agriculture (USDA) Organic Seal, a product must be at least 95% organic; that is, at least 95% of the ingredients used must be organic. The remaining 5% can include non-organic items (if an organic option for that product is not commercially available) but cannot include any genetically modified organisms (GMOs)(http://www.scsglobalservices.com/organic-certification?).

For tea, only N has been found to show yield response, hence all manure/compost experiments have concentrated on determining the manure rates on the N-content. In the case of studies using inorganic fertilizer, the other nutrients like P, K and S, are included in the formulations as insurance to the other nutrient deficiencies that may occur. Fortunately, the concentrations of P and K in manures are normally adequate although it is dependent on the source (Table 1).

This paper summarizes results of two long term studies comparing different sources of organic manures assessed for yields, soil and tea quality parameters as a way of showing potential of markets for diversified Kenyan tea products.

MATERIALS AND METHODS

Case Study 1: Evaluation of sheep manure and inorganic fertilizers on yields and soil properties in clone TRFK 31/8 at Kericho

The experiment was started from planting in 1985 at TRFK-Timbilil Estate, Kericho, Latitude $0^{0}22'$S, Longitude $35^{0}21'$ E, located at an altitude of 2180 m asl using high yielding clone TRFK 31/8 tea plants at a spacing of 4 x 2 sq ft. The site was previously an indigenous forest. The trial was laid out in a randomized complete block (RCBD), replicated three times with the treatments being; i) organic manure at 4 rates (60, 120, 180, 240 kgN/ha), ii) enriched organic manure-DAP ratio 8:1 at 4 rates (60, 120, 180, 240 kgN/ha), iii) enriched organic manure-DAP ratio 4:1 at 4 rates (60, 120, 180, 240 kgN/ha), iv) control (0 N kg/ha) and, v) NPKS 25:5:5:5 (at rate of 180 kgN/ha). Organic manures were applied in the form of dry, well-rotted sheep manures.

Each net plot comprised 5 x 8 bushes and was surrounded by a guard row of tea bushes. The inorganic manures (NPKS 25:5:5:5 and DAP) were applied during April/May season, while the organic manures were applied during the September/October season to avoid loss of nitrogen through volatilization of ammonia. Tea was plucked at seven to ten days intervals and weight per plot recorded at every plucking round. The trial was assessed for yields in 2009 and 2012, since year 2010 was a prune year.

Case Study 2: Effects of organic manures and in-organic fertilizers on clone TRFK 31/8 grown in strongly acid soils, Kangaita

The trial using clone TRFK 31/8 was established in the year 2000 at Kangaita, Latitude 0° 26' S, Longitude 37° 15' E, and altitude of 2020 m above mean sea level on the slopes of Mount Kenya at East of Rift Valley, Kenya, to evaluate the effect of enriched manures in tea. The soils are red clay classified as humic acrisols [14]. The experiment was a 4 x 4 factorial design laid out in a randomized complete block (RCB) design and replicated three times. Each plot comprised of 7 by 14 bushes spaced at 1.22 by 0.61 m^2. The whole trial was surrounded by a complete guard-row of tea bushes. The inorganic fertilizer was applied first week of September every year while organic manure were applied third week of September every year to avoid loss of nitrogen through volatilization of ammonia.

The experimental treatments were: T1: cattle manure at equivalent rates of 0, 75, 150 and 225 kg N ha^{-1} $year^{-1}$, T2: NPKS 25:5:5:5 at rates of 0, 75, 150 and 225 kg N ha^{-1} $year^{-1}$, T3: (T1: T2) at a ratio of 1:2 and equivalent rates of 0, 75, 150 and 225 kg N ha^{-1} $year^{-1}$ and T4: (T1: T2) at a ratio of 1:4 at equivalent rates of 0, 75, 150 and 225 kg N ha^{-1} $year^{-1}$. The inorganic fertilizer was applied during the first week of September while organic manure was applied the third week of the same month to avoid loss of nitrogen through volatilization of ammonia. Fertilizer and manure application was applied once a year. The organic manures were standardized based on N content. Cattle manure and soil were analyzed for chemical composition using standard methods as described by Okalebo *et al.* (2002), before the treatments were applied (Table 2). The trial was assessed for yields in the second and third years after prune in 2010 and 2011.

In each of the two experiments, an equation ($n \times a \times 0.225)/b$ was used to convert yield per plot to kg mt/ha/year; where n was the green leaf yield per plot, a is the plant population per hectare, b is the number of plants per plot, and 0.225 the factor converting green leaf to made tea (TRFK, 2002).

Laboratory and data analysis

The soils were sampled with a soil corer at the different soil depths prior to pruning of the tea bushes in 2009 and 2008, for experiments *i* and *ii*, respectively. pH was measured using an electrode pH meter on a 1:1, soil: water ratio. The soil available K was extracted using 1M ammonium nitrate solution at a soil: extractant ratio of 1:2.5 (TRFK, 2007) and K analysed using an atomic absorption spectrophotometer (AAS) with an air-acetylene flame. The organic manures were characterized for their chemical composition using standard methods (Okalebo *et al.*, 2002). The soil textural analysis was done using bouyoucos hydrometer method.

For black tea, plain quality parameters, two kilograms of two leaves and a bud were plucked for theaflavins (TFs) and thearubigins (TRs) determination using the Robert and Smith (1963) method. Caffeine content was analysed by colorimetric method using spectrophotometer (Kekana, 2013; TRFK, 2007). The yield and soil data from the plots were subjected to ANOVA using MSTAT-C (1993) statistical software package.

RESULTS AND DISCUSSION

Characteristics of the organic manures

The chemical characteristics of the two types of organic manures used, that is, sheep and cattle are presented in Table 2. Manure quality is generally dependent on the type of animal housing, storage strategies and feed provided to the farm animals, and the nutrient concentrations serve as a good indicator of quality (Lekasi *et al.*, 2001). Therefore, the sheep manure with higher contents of organic C, N, P, K and Ca is of better quality compared to the cattle manure. Since the manures are applied based on the N-content annually, it implies that the higher content of the other nutrients (such as P, K, Ca, Mg) in the sheep manure compared to cattle manure are lowered considerably at the application level.

Table 2: Some characteristics of the organic manures.

Source	pH	%Organic C	%N	%P	%K	%Ca	%Mg	C:N
Sheep	7.6	27.5	1.72	0.62	1.80	1.09	0.60	16
Cattle	7.3	22.8	1.04	0.28	1.31	0.89	0.24	22

Soil physical characteristics

The particle size distribution of the two soils is presented in Table 3. While, the Kericho soil was deep, acidic, well drained friable clay, the Kangaita soil was characterized as loamy sand with high percentage sand and low clay content. The distribution of soil particles plays a role in the adsorption of water and nutrients. Attraction of the particles to each other is surface dependent (Brady and Weil, 2002). The Kangaita tea soils are well aerated with low non-reactive surface areas that are not able to stabilize organic matter to a high degree and prone to nutrient leaching (Okalebo *et al.*, 2002) while the Kericho clay soils have high total surface area good for nutrient supply and retention.

Table 3: Particle size distribution and textural class of the two sites.

Site	Particle size	% distribution	Soil textural class
Timbilil Estate, Kericho	Clay	59	Clay
	Sand	32	
	Silt	9	
KTDA Tea Farm, Kangaita	Clay	6	Loamy sand
	Sand	78	
	Silt	16	

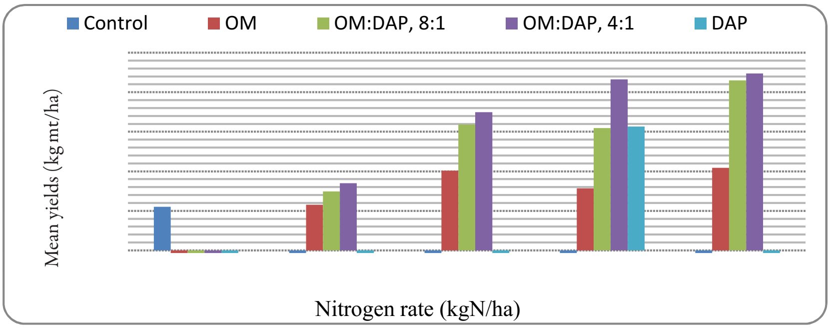
Effect on tea yields

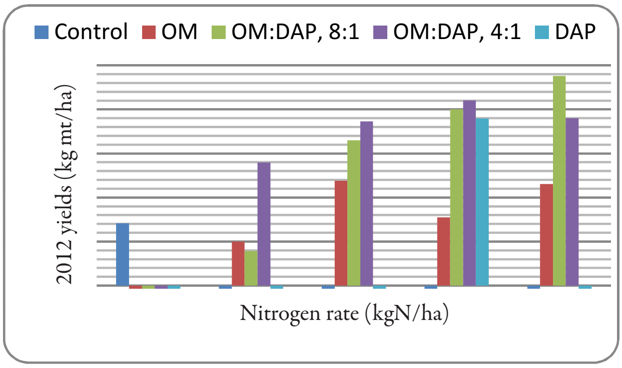
Kericho site

The variations in yields due to the different organic and inorganic fertilizer treatments and nitrogen rates at Kericho site are presented in Figure 1. Both the 2009 and 2012 yields, significantly ($P < 0.05$) varied with treatments type. The enriched organic manures showed significantly better yields than the organic manure alone. Indeed, in both years, the more the enriching with DAP, ratio 8:1, and ratio 4:1; the better were the yields at 6018 and 4106 kgMT/ha, and 6500 and 4316 kgMT/ha, respectively. The enriched organic manure at the ratio of 4:1 at the 180 kgN/ha rate had significantly higher yields (7328 and 4601 kgMT/ha) than the NPKS 25:5:5:5 (6134 and 4398 kgMT/ha) at the same rate but was similar to the 8:1 enrichment ratio (6096 and 4502 kgMT/ha). However the yields were similar with the enriched organic manure at the ratio of 8:1. This trend was not seen in the prune cycle means, where the NPKS mean yields of

4569 kgMT/ha were lower than the two enriched organic manures of 5096 and 5020 kgMT/ha for the ratio 8:1 and 4:1, respectively, at the 180 kgN/ha rate. The control treatment generally showed very low yields in both years showing the importance of fertilizer application in tea cultivation. The yield trends were generally reproduced for the two years studied implying that inorganic fertilizers at this site may result to better yields and that enriching organic manures has a yield advantage which is even superior to use of inorganic fertilizers alone.

The results demonstrate that although the organic manure does not give high yield responses compared to the enriched manure treatments, a rate of 120 kgN/ha would suffice to replenish the lost nutrients thus maintaining bush health and also give better yields.



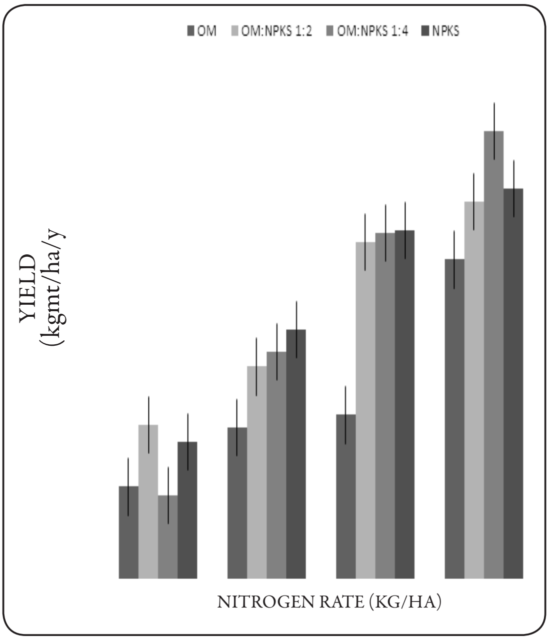


2009	Nil/ NPK vs all	Rate	Type	T x R	2012	Nil / NPK vs all	Rate	Type	T x R
CV (%)	10.0	9.9	9.9	9.9	CV(%)	8.84	8.5	8.5	8.5
LSD, $P = 0.05$	671	393	341	681	LSD, $P = 0.05$	572	324	281	NS

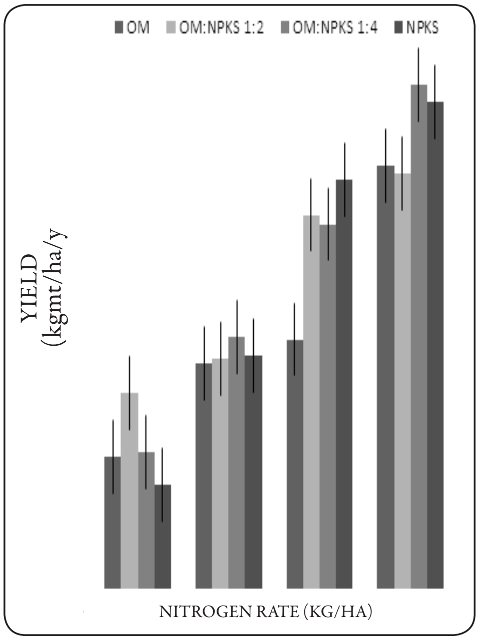
Figure 1: Effects of fertilizer type and rate on the yield of tea in 2009 and 2012.

Kangaita site

There was response of yield to nitrogen fertilizers, implying that the soil alone cannot sustain high yields. The yields of tea varied significantly with fertilizer type and rate in 2010 (Figure 1a), however in 2011 fertilizer type was not significant (Figure 1b). The annual crop yield variation is a common characteristic of tea where several factors including temperatures, rainfall, amount of rainfall and distribution vary [29]. In 2011, lower rainfall was received which resulted in lower yields compared to year 2010. Enriched manures had the highest yield followed by NPKS and organic manure especially at higher fertilizer rates. The response of tea yield to the increase in N fertilizer rate has been reported in several studies [12, 38]. The increase in yield with enriched manures is consistent with the principle that ISFM results in improved nutrient retention and nutrient release patterns thus increasing yield. The low nutrient status coupled with the slow release of nutrients from organic manure maybe responsible for the low yields. This shows that organic manure or NPKS alone cannot sustain tea production.



a) Year 2010



b) Year 2011

Figure 2: Effects of fertilizer type and rate on the yield of tea in 2010 and 2011.

Effects on soil pH

Kericho site

The effects of the various treatments and rates on the soil pH at the upper (0 – 10 cm, 10 – 20 cm, 20 – 30 cm, and deeper 40 – 60 cm) depths for the Kericho site are summarized in Table 4. The organic manure increased the pH levels with a mean of 5.55 as compared to the enriched manures. The non-applied control treatment, had a significantly lower soil pH of 4.85, while the NPKS 25:5:5:5 at the 180 kgN/ha rate was most acidic at 3.99. Where inorganic fertilizer was enriched, the soil pH generally became more acidic with increase in the N-rates at the three upper depths confirming that inorganic nitrogenous tea fertilizers cause soil acidification proportional to the added amounts as reported in other studies (Kamau *et al.*, 2008; Wanyoko, 1997). A significant interaction was seen between the types and rates at the surface soil (0 – 10 cm) where pH due to the sheep manure treatment increased with N-rates while the enriched treatments became more acid. The deeper soil depth did not reveal any significant differences among the treatments. However, the control and the NPKS 25:5:5:5 showed the same trend patterns as in other depths.

Table 4: Effects of organic manure, enriched organic manures and NPKS fertilizers on soil pH at different depths at Kericho.

Soil pH depth	Fertilizer type	Fertilizer rate (kg N/ha/year)					Manure mean
		0	60*	120*	180*	240*	
0-10 cm	Nil applied	4.85#	–	–	–	–	–
	Organic manure (OM)*	–	5.59	5.46	5.69	5.46	5.55*
	OM:DAP, ratio 8:1*	–	5.07	4.92	4.48	4.70	4.79*
	OM:DAP, ratio 4:1*	–	4.98	4.53	4.40	4.04	4.49*
	NPKS 25:5:5:5	–	–	–	3.99#	–	4.87@
	Mean N-rate	–	5.21*	4.97*	4.86*	4.73*	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 4.66 0.27		Type (*) 4.34 0.13	Rate (*) 4.34 0.15	Type x Rate (*) 4.34 0.26	
10-20 cm	Nil applied	4.57#	–	–	–	–	–
	Organic manure (OM)*	–	5.40	5.31	5.94	5.52	5.54*
	OM:DAP, ratio 8:1*	–	5.17	4.85	4.94	5.03	5.00*
	OM:DAP, ratio 4:1*	–	5.13	4.71	4.52	4.27	4.65*
	NPKS 25:5:5:5	–	–	–	4.09#	–	4.96@
	Mean N-rate	–	5.23	4.95	5.13	4.94	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 6.55 0.39		Type (*) 6.56 0.20	Rate (*) 6.56 NS	Type x Rate(*) 6.56 NS	
20-30 cm	Nil applied	4.29#	–	–	–	–	–
	Organic manure (OM)*	–	4.83	4.85	5.35	5.18	5.05*
	OM:DAP, ratio 8:1*	–	5.06	4.50	5.04	5.01	4.90*
	OM:DAP, ratio 4:1*	–	4.78	4.61	4.48	4.26	4.53*
	NPKS 25:5:5:5	–	–	–	3.90#	–	4.72@
	Mean N-rate	–	4.89	4.65	4.96	4.82	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 8.53 0.48		Type (*) 8.79 0.25	Rate (*) 8.79 NS	Type x Rate (*) 8.79 NS	
40-60 cm	Nil applied	4.25#	–	–	–	–	–
	Organic manure (OM)*	–	4.56	4.67	5.12	5.03	4.85*
	OM:DAP, ratio 8:1*	–	5.01	4.52	5.04	4.88	4.86*
	OM:DAP, ratio 4:1*	–	5.11	4.33	4.61	4.58	4.66*
	NPKS 25:5:5:5	–	–	–	4.11#	–	4.70@
	Mean N-rate	–	4.89	4.51	4.92	4.83	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 8.84 NS		Type (*) 9.22 NS	Rate (*) 9.22 NS	Type x Rate (*) 9.22 NS	

* Differences between the fertilizer types or rates; # Differences between nil and NPKS 25:5:5:5 and all other treatments; @ Depth mean

Kangaita site

Soil pH was significantly affected by fertilizer type and rate (Figure 3). Compared to the control, addition of NPKS followed by enriched manures, reduced the soil pH especially at higher fertilizer rates in the top soil (0 – 10 cm) and down the soil profile where pH was higher (40 – 60 cm). This result confirms that application of inorganic nitrogenous fertilizers at high rates decrease soil pH (Kamau *et al.*, 2011). On the other hand, addition of organic manure increased the soil pH in the top soil (0 – 10 cm). Oxidation of organic acid anions is generally considered the main contributor to increased soil pH (Noble *et al.*, 1996). Higher soil pH with organic manure is probably due to organic acid anions which might complex the Al^{3+} ions that contribute to soil acidity. Shisanya *et al.* (2009) also observed a decline in soil pH after two years of using inorganic and enriched manures than when using organic manures.

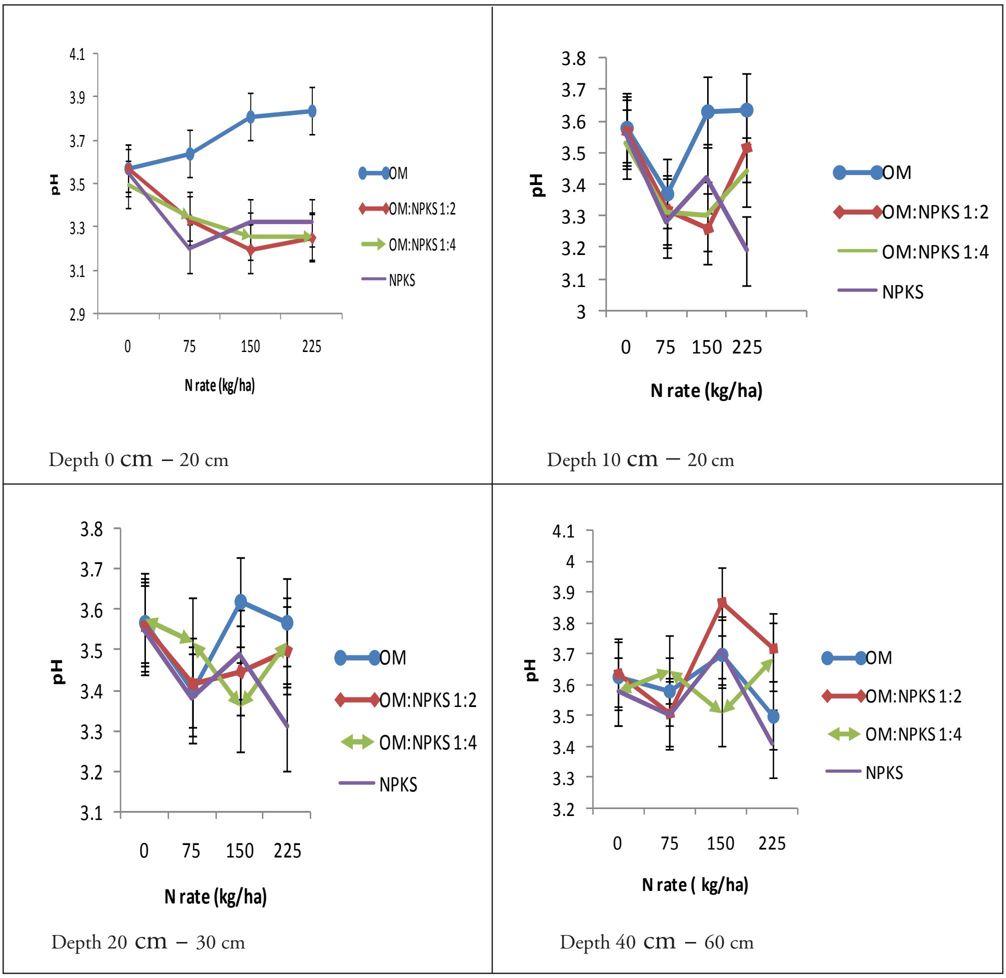


Figure 3: Effect of fertilizer type and rate on soil pH at different soil depths at Kangaita.

Effects on soil extractable K

Kericho site

The effects of the various treatments and rates on the soil extractable K at the 0 – 10 cm, 10 – 20 cm, 20 – 30 cm, and 40 – 60 cm depths are summarized in Table 5. To lower the resulting high coefficient of variations (CV) arising from the variability in tea soils (Smith, 1962, Kamau *et al.*, 2004), data transformation using $Log_e(x + 1)$ was performed. The available K in the organic manure treatments were significantly higher than the control and NPKS treatment at all the soil depths. At the same time, the NPKS applied treatment at 180 kgN/ha was also lower than the control treatment at the upper soil depths, showing that there is leaching of the two base nutrients to the lower soil depths. Generally, the organic manure treatment had higher available K levels indicating that it has a potential in stabilizing these nutrients in tea plantations, implying a more stable ecosystem. Past studies on the effect of organic manures and inorganic fertilizers on black tea quality showed that there were no differences in tea quality (Owuor and Obanda, 1996). Considering that livestock manures are used in over 95% of the smallholder farmers in the Kenyan highlands (Karanja *et al.*, 1997; Lekasi *et al.*, 2001), the utilization of such manures in tea farms would also assist to amend the soil in terms of soil acidity and improving on the base nutrients.

Table 5: Effects of organic manure, enriched organic manures and NPKS fertilizers on extractable K at different depths at Kericho.

Soil pH depth	Type	Rate (kg N/ha/year) 0	60*	120*	180*	240*	Manure mean
0 – 10 cm	Nil applied	709 (6.57)#	–	–	–	–	–
	Organic manure (OM)*	–	1072 (6.96)	1314 (7.17)	1228 (7.11)	1136 (6.97)	1187 (7.05)*
	OM:DAP, ratio 8:1*	–	1005 (6.91)	1018 (6.92)	880 (6.77)	899 (6.76)	951 (6.84)
	OM:DAP, ratio 4:1*	–	1252 (7.12)	1116 (7.00)	1265 (7.11)	925 (6.82)	1140 (7.01)
	NPKS 25:5:5:5	–	–	–	504 (6.21)#	–	1023 (6.88)@
	Mean N-rate	–	1109 (7.00)	1149 (7.03)	1124 (7.00)	987 (6.85)	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 3.73 (0.30)		Type (*) 3.84 NS	Rate (*) 3.84 NS	Type x Rate (*) 3.84 NS	
10 – 20 cm	Nil applied	644 (6.44)#	–	–	–	–	–
	Organic manure (OM)*	–	1310 (7.15)	1064 (6.97)	1458 (7.28)	1072 (6.92)	1226 (7.08)*
	OM:DAP, ratio 8:1*	–	908 (6.81)	1057 (6.96)	910 (6.74)	808 (6.66)	921 (6.79)*
	OM:DAP, ratio 4:1*	–	1009 (6.92)	1068 (6.97)	1013 (6.92)	944 (6.84)	1009 (6.91)*
	NPKS 25:5:5:5	–	–	–	400 (5.99)#	–	976 (6.83)@
	Mean N-rate	–	1076 (6.96)	1063 (6.96)	1127 (6.98)	941 (6.81)	
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 3.50 (0.28)		Type (*) 3.30 (0.14)	Rate (*) 3.30 NS	Type x Rate(*) 3.30 NS	
20 – 30 cm	Nil applied	358 (5.87)#	–	–	–	–	–
	Organic manure (OM)*	–	1105 (6.96)	798 (6.68)	1513 (7.27)	1412 (7.21)	1207 (7.03)*
	OM:DAP, ratio 8:1*	–	855 (6.74)	887 (6.75)	706 (6.55)	812 (6.68)	815 (6.68)*
	OM:DAP, ratio 4:1*	–	840 (6.73)	860 (6.75)	1060 (6.96)	1011 (6.92)	943 (6.84)*
	NPKS 25:5:5:5	–	–	–	384 (5.94)#	–	900 (6.72)@
	Mean N-rate	–	933 (6.81)	848 (6.73)	1093 (6.93)	1078 (6.94)	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 3.70 (0.29)		Type (*) 3.75 (0.15)	Rate (*) 3.75 NS	Type x Rate (*) 3.75 NS	
40 – 60 cm	Nil applied	326 (5.78)#	–	–	–	–	–
	Organic manure (OM)*	–	834 (6.71)	1087 (6.94)	1306 (7.16)	1109 (6.92)	1084 (6.93)*
	OM:DAP, ratio 8:1*	–	664 (6.50)	705 (6.55)	629 (6.44)	693 (6.54)	673 (6.51)*
	OM:DAP, ratio 4:1*	–	776 (6.64)	632 (6.45)	891 (6.79)	891 (6.79)	798 (6.67)*
	NPKS 25:5:5:5	–	–	–	373 (5.89)#	–	780 (6.58)@
	Mean N-rate	–	758 (6.61)	808 (6.65)	942 (6.80)	898 (6.75)	–
	C.V. (%) LSD (P = 0.05)	Nil or NPKS vs. all (#) 3.65 (0.29)		Type (*) 3.57 (0.14)	Rate (*) 3.57 NS	Type x Rate (*) 3.57 NS	

Figures in parenthesis are $log_e(x + 1)$ transformations.
*Differences between the fertilizer types or rates.
Differences between nil and NPKS 25:5:5:5 and all other treatments.

Kangaita site

The soil extractable K was significantly affected by fertilizer type and rate (Figure 4). Organic manure had the highest extractable K^+ followed by NPKS and lastly enriched manures. K levels were similarly higher in the top soils (0 – 10 cm) compared to the deeper soils (40 – 60 cm). The results were expected because organic manure supplies K^+ on mineralization and also have the acid humus that helps in adsorption of K^+ leading to reduced leaching (Barbora, 1991). The lower K associated with enriched manures and NPKS is probably due to of large quantities of NH_4^+-N ions relative to K^+ ions in the nitrogenous fertilizer. K will therefore be removed from both exchange sites and through leaching. Similar findings were reported by Kamau *et al.* (2011) where lower soil K^+ was observed in NPKS applied plots compared to the control. The soil extractable K showed the same trend as P with increasing rates of fertilizers. The K level tended to decrease with increasing rate of fertilizer at 0 – 10 cm depth but was the opposite at 40 – 60 cm. In Kangaita area, leaching of K in the soil after a four year study has not been reported to be major problem when using NPKS 25:5:5:5 (Dogo *et al.*, 1994). Therefore, the decrease in K content in the soil with increase in fertilizer rate may be due to the low CEC and high Al^{3+} ion saturation (high soil acidity) caused by replacement of K^+ by NH_4^+ due to the same ionic radii (Dogo *et al.*, 1994; Garrison, 1990).

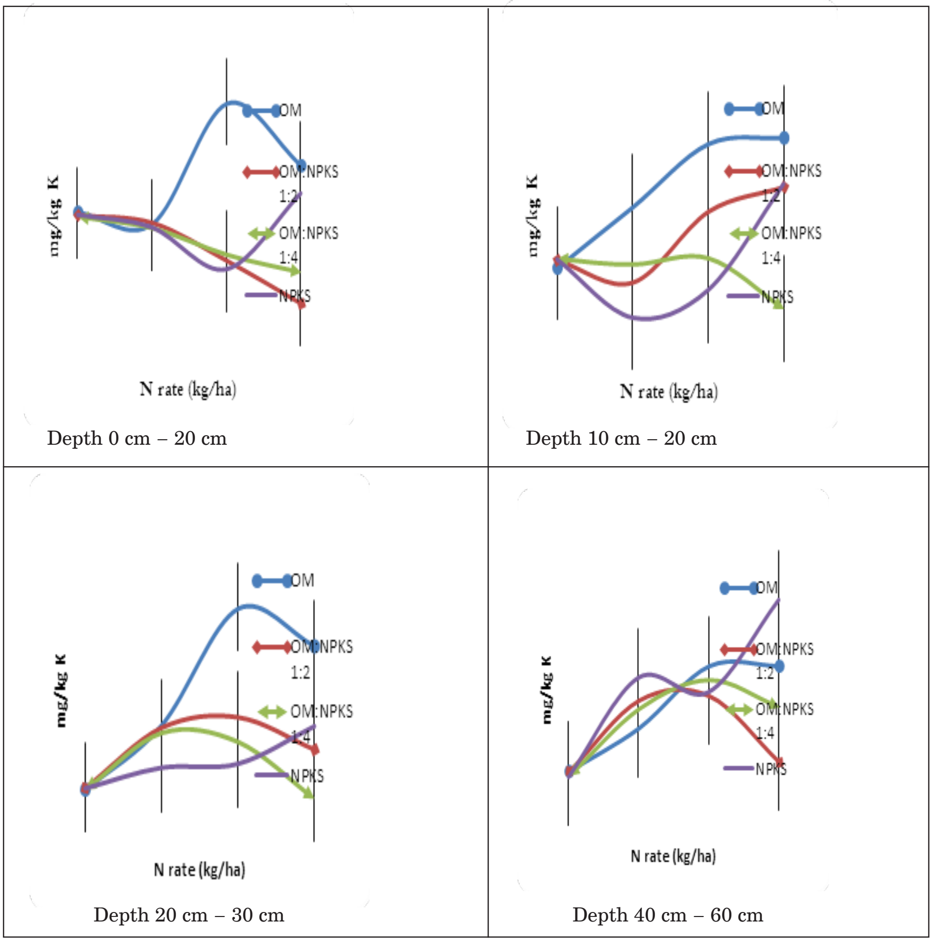


Figure 4: Effect of fertilizer type and rate on soil extractable K content at different soil depths.

Effects on tea quality parameters

The analysis on theaflavins, thearubigins and caffeine in the made tea were only done for the Kangaita site.

Theaflavins

Theaflavin is the plain black tea parameter responsible for the astringency (briskness) and brightness of black tea (Owuor *et al.*, 2006; Wright *et al.*, 2002). Fertilizer type did not significantly affect the TF content (Figure 5). This is due to the fact that the fertilizers were applied based on nitrogen which impairs black tea quality (Owuor, 1997). Fertilizer rate however significantly reduced the TF content. Increase in nitrogen rate increases accumulation of free amino acid and decrease the production of catechins. The presence of free amino acid favours green tea quality while the presence of catechins favours the black tea quality (Mukai *et al.*, 1992). The production of catechins is linked to the availability of sugars. In a non-fertilized plot, the increase of TF is due to accumulation of carbohydrate to the carbon skeleton which leads to increase in phenolic compounds responsible for production of catechins (Choudhury *et al.*, 1991). The decrease in TF content with increase in nitrogen rate was more pronounced with NPKS and enriched manures than organic manures. This implies that N applied in the form of inorganic fertilizers increase the accumulation of amino acid and fatty acid and reduces the catechins levels which lead to the production of black tea with low TF levels. Owuor *et al.* (2010) similarly found that increase in NPK fertilizer rates lowered TF levels on clone BBK 35 growing at different tea growing areas of Kenya.

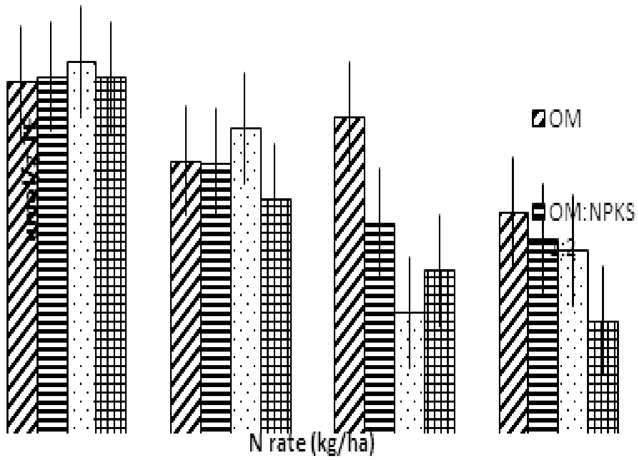


Figure 5: Effect of Fertilizer type and rate on Theaflavin (TF) content in made tea.

Thearubigins

Thearubigins are important plain black tea parameter that contributes to colour and thickness (mouth-feel). Fertilizer type and rate did not significantly affect the TR content in the made tea (Figure 6). Owuor *et al.* (2010) reported similar findings on fertilizer type and rate. Thearubigins have not shown a significant relationship with black tea quality, hence the precursors and route of information about the effect of fertilizers on TR is relatively unknown (Owuor *et al.*, 2010; TRFK, 2002).

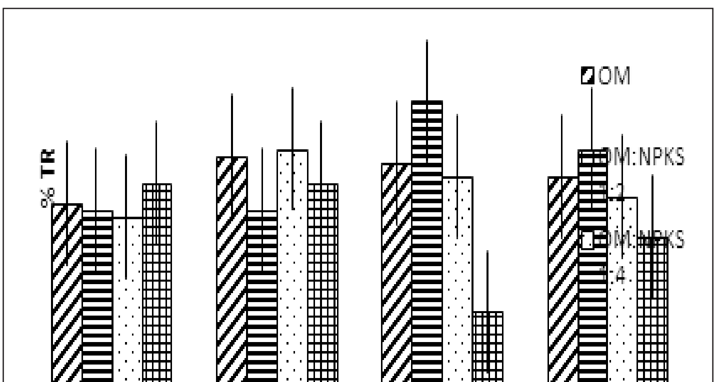


Figure 6: Effects of fertilizer type and rate on thearubigins (TR) level (%) content in made tea.

Caffeine content

Caffeine is an important plain black tea quality parameter responsible for the stimulatory effects. Fertilizer type and rate significantly affected the caffeine content (Figure 7). Control plots had the lowest caffeine content followed by organic manure, enriched manures and lastly NPKS. The lower caffeine content in the plot receiving organic manures may be due to slow release of nutrients while in the control plots may result from an adequate supply of nutrients. Increased caffeine content with addition of enriched manures and NPKS may be due to readily available nutrients. In Kenya, Owuor (1987) reported a linear increase in caffeine content with increase in NPK fertilizer rates up to 450 kg N/ha, which was similar to Choundry *et al.* (1991) in North Eastern India. The caffeine content of the Kenyan tea growing in the highlands of the west of Rift Valley ranged from 2.64% to 4.0% (Owuor and Obanda, 1998). Generally, the results of this study showed lower caffeine content ranging from 1.33% to 1.81% which may result from the locality, that is, East of Rift Valley. Enriching manures increased the caffeine content in the made tea but in a lower level than the NPKS. The increase in caffeine content with increase in nitrogen fertilizer rate is due to increased N metabolism which favours the synthesis of amino acid and caffeine (Mukai *et al.*, 1992).

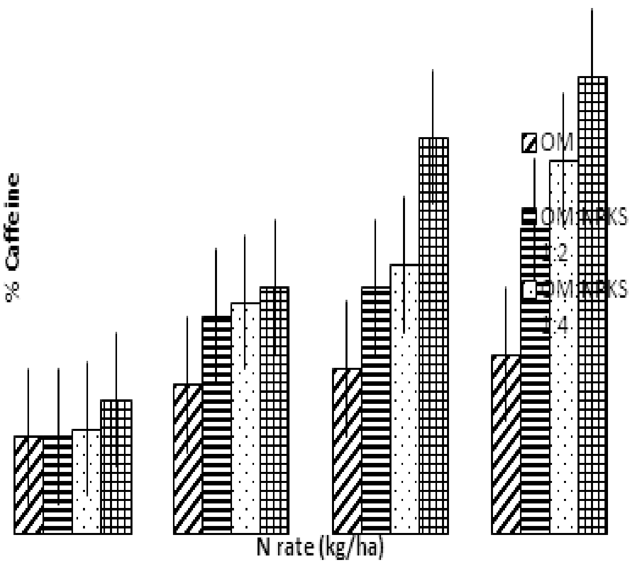


Figure 7: Effects of fertilizer type and rate on caffeine level (%) content in made tea.

CONCLUSIONS

The yield results from the two trials demonstrate that although the organic manures do not give high yield responses as compared to the enriched manure treatments, a rate of 120 – 150 kgN/ha would suffice to replenish the lost nutrients thus maintaining bush health and also give better yields. Use of organic manure resulted in higher soil pH and extractable K in the soil, demonstrating that the organic manures can maintain the acidity levels of the soils thus addressing the often controversial land sustainability problem arising from application of external inputs in tea agro-ecosystems. Organic manures and enriched manures increased the TF and TR content while caffeine increased with increase in nitrogen rates. This was more pronounced when using inorganic fertilizers and enriched manures. Enriched manures can, therefore, be recommended for use instead of either inorganic fertilizer (NPKS) or organic manures alone to enhance tea production as the case of integrated soil fertility management.

These results therefore confirm that if the tea farming community is to be pro-active in preserving ecological harmony and promoting biological diversity, then use of organic manures as a source for nutrients is the future. However, the tea growers have to be compensated by benefiting from premium organic tea prices due to the loss in yields as seen by the higher yields arising from the enriched manures, hence the need for promotion of the organic and low carbon tea industry.

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