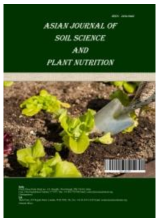

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Influence of Organic Enriched Manure and Inorganic Fertilizers on Plant Physiological Processes of Kenyan Tea Clone

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Authors' contributions

This work was carried out in collaboration among all authors. Author HK designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors NKK, NK and JPGO reviewed the study design and all drafts of the manuscript. Author NKK managed the analyses of the study and performed the statistical analysis. Author HK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Tea (*Camellia sinensis* L.) is one of the most popular beverages consumed in the world and Kenya is the leading exporter in Africa and only 3rd worldwide after China and India. Nutrient deficiency in soils and poor fertilization are possibly two reasons for low yields and quality of tea. The use of organic matter and mineral fertilizers has been proved to be a sound soil amendment and fertility management strategy. Therefore, this study was conducted to evaluate the possibility of using readily available organic manures in combination of inorganic fertilizers on the physiological processes of tea clones in Kenya. The study was conducted within Timbilil estate, KALRO- Tea Research Institute in Kericho County on variety clone TRFK31/8. It was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. There were 14 treatments that

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randomly assigned in each block. Data on tea response was determined from photosynthesis rate, transpiration rate and stomatal conductance then recorded and analyzed using GenStat Version 15.1. There were significant differences between the treatments on the transpiration rate, stomatal conductance and the photosynthetic rate in both seasons for all the months recorded. The transpiration rate was highest during the wet season in the months of June, July and August while lower transpiration rates were recorded during the dry season in the months of December, January and February with 0.1 g m^{-2} s^{-1} transpiration rates recorded in several treatments in the month of February. Stomatal conductance, photosynthetic rate and transpiration rate were higher where NH_4^+ was introduced through the organic manure in all the seasons and therefore confirms that it is highly important to incorporate soil amendments with higher organic matter in tea production in Kenya.

Keywords: Tea; physiological processes; organic; manure; stomatal conductance; inorganic fertilizers; photosynthetic rate.

1. INTRODUCTION

Tea (*Camellia sinensis* L.) is a perennial shrub belonging to the *Camellia* genus of the *Theaceae* family [1]. Its production is the leading foreign exchange earner in Kenya contributing about 26% foreign exchange and 4% GDP. Tea is planted in an area of over 157,720 hectares, with production of about 345,817 metric tonnes of made tea. Over 325,533 metric tonnes exported. Over 49 varieties so far developed and fertilizers are regularly added to replenish soil nutrients. Tea requires high levels of soil nutrients, particularly N, P, K, Ca and Mg [2,3,4] since the deficiency of these nutrients could adversely affect the yield and quality. Obatolu [5] observed that N rate of 150 kg/ha/year for tea plant proved better for optimum growth and yield while Ipinmoroti et al. [6] reported that using both organic and inorganic fertilizer materials improved tea plant growth performance. A combined balanced application of inorganic fertilizer and supplementary dose of organic matter sustains the crop productivity [7] and maintain the soil fertility [8]. Integrated supply of nutrients to plants through organic and inorganic sources is becoming an increasingly important aspect of environmentally sound agriculture because nutrients contained in organic manure are released slowly and stored for a longer time in the soil, thereby ensuring a longer residual effect and persistence of nutrient availability [8]. For improvement of soil condition and maintenance of soil health while maintaining optimum production, there is a need to reduce the application of costly fossil fuel based inorganic fertilizers, which have significant adverse influence on the environment. The use of organic matter and mineral fertilizers has been proved to be a sound soil amendment and fertility management strategy. The quality of tea is greatly influenced by both agro-climatic condition and nutrient management [8].

Tea production is optimized by nutrient supply through inorganic fertilizers at rates between 150 –300 kg N ha^{-1} for black tea (fermented tea) [9]. These rates are high and accounts to about 50% of the total annual farm variable inputs [10]. Presently, there is a global short supply and high procurement cost of inorganic fertilizers and the poor resource farmers cannot afford this. Heavy application of inorganic fertilizers leads to deterioration of soil cation exchange capacity [11] (CEC) and clay contents of the soil, high concentration of aluminum (Al) and silicate in drainage water in addition to air pollution through nitrous gas emission and excessive leaching leading to underground water pollution.

Most tropical soils are low in organic matter content and need proper organic matter management by application of organic fertilizer for sustainable long term land use. The decline in yield under long term tea cultivation reflects degradation of soil quality. This is due to poor soil conservation practices that are necessary for sustaining soil quality and tea crop production which is interlinked with plant physiological processes [12]. Previous research into use of integrated methods of fertilization has been limited in scope. Therefore, this study will be able to generate information that will help farmers to use fertilizers in the best applicable method with increased plant nutrient use efficiency.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted within Timbilil estate, KALRO- Tea Research Institute. The site lies along the incline of Mau forest ranges in the Rift valley at an altitude of 2178 m above mean sea level, latitude of 0°22' South and a longitude of 35°21' East. The annual rainfall ranges between 1200 - 2700 mm and mean monthly air temperatures of 16.1°C - 19.5°C. The area experiences three distinct seasons, ranging from the warm dry season (Dec. to Mar.), cool wet season (April to Aug.) and the warm wet season (Sept. to Nov.). The soils are well-drained, deep dusky red to dark reddish brown, friable clay with acid humic topsoil classed as humicnitisols. The tea variety used was CLONE TRFK 31/8.

2.2 Experimental Design and Treatments

The study employed multifactorial Randomized Complete Block Design (RCBD) replicated thrice. According to Hinkelmann and Kempthorne [13] the design is significant because it will aid in grouping similar experimental units. In this regard, it helps keep the units as uniform as much as possible. The study was superimposed on an on-going experiment investigating effects of different types of fertilizers on tea yields started in 1985 with TRFK 31/8 planted high yielding clone. The entire experimental plot was divided into three blocks each containing 14 plots. The total experimental area was 157.67 m^2. Each plot comprising of 10 tea bushes spaced at 4 × 2 × 2 m^2. The whole plot was surrounded by complete guard-rows of tea bushes. Inorganic and enriched fertilizers were applied once a year. The sheep manure was standardized based on Nitrogen content. Sheep manure chemical composition was analyzed before application and experimental field plot soil texture analyzed. The 14 treatments that randomly assigned in each block as follows: 0 kg N/ha; Sheep manure 60 kg N/ha; Sheep manure 120 kg N/ha; Sheep manure 180 kg N/ha; Sheep manure 240 kg N/ha; 4 sheep manure:1 Di-Ammonium Phosphate (DAP) at 60kg N/ha; 4 sheep manure:1 DAP at 120 kg N/ha; 4 sheep manure:1 DAP at 180 kg N/ha; 4 sheep manure:1 DAP at 240 kg N/ha; 8 sheep manure:1 DAP at 60kg N/ha; 8 sheep manure:1 DAP at 120 kg N/ha; 8 sheep manure:1 DAP at 180kg N/ha; 8 sheep manure:1 DAP at 240 kg N/ha and NPK 180 Kg/ha. The enriched organic fertilizer were of two types; the first type involve enriching with DAP in the ratio of 4:1 (4 Nitrogen content in sheep manure: 1 Nitrogen content in DAP). The second type involved enriching with DAP in the ratio of 8:1 (8 Nitrogen content in sheep manure: 1 Nitrogen content in DAP).

2.3 Data Collection and Analysis

Data on tea response was determined from photosynthesis rate, transpiration rate, stomatal conductance and yields recorded during wet dry season of December in 2014/2015 and dry season of January and February in 2014/2015 seasons and wet seasons of April and May 2015. Data was collected at different times and intervals depending on the parameter being investigated; photosynthesis rate, transpiration rate, and stomatal conductance were recorded thrice a month using TPS 2 photosynthetic system (CIRAS-3 model) using randomly selected three leaves per plot and using a total of nine leaves per month. The third leaf was used where three leaves were randomly selected per plot. The data collected was refined, tabulated and subjected to Two-Way Analysis Of Variance (ANOVA) using GenStat Version 15.1 to test significance. The means were separated using Fisher's Least Significance Difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Transpiration Rate

There were significant differences ($P \leq 0.05$) between the treatments in both seasons on the transpiration rate during the months of June and August (Table 1). The highest transpiration rates were recorded in different treatments without a consistent trend; however the untreated control exhibited the lowest transpiration rate throughout the months in both seasons of the trial where the dry season showed higher transpiration rates of up to 500% compared to the wet season. The highest rate was during the month of January during the dry season while the lowest was during the wet season in the month of August (Table 1).

The evaporation of water from leaf surfaces, also known as transpiration, drives the movement of water through the plant's xylem. The tension and cohesive and adhesive forces of the water allows it to overcome the gravitational forces working to pull the water column down the plant and this explains why the transpiration was higher during the wet season compared to the dry season. As a consequence of photosynthesis, plants lose water rapidly via transpiration. However, transpiration may benefit the plant by facilitating nutrient uptake and transport through the xylem. Plants use a copious amount of water while photosynthesizing through transpiration. The amount is so large that plant biologists have stigmatized transpiration as a "necessary evil" that is inextricably linked to carbon dioxide (CO_2) absorption [14]. This supports [15] who found out that Potash plays an important role in water retention by the plant. It also regulates the opening and closing of stomata.

3.2 Stomatal Conductance

The stomatal conductance was higher in the wet season compared to the dry season where the month of July had the highest stomatal conductance rate while 0.2 mmol $m^{-2}s^{-1}$ conductance rates were observed in the month of February in the dry season under several levels. However, no trends were consistent through the months although the zero application of organic or inorganic fertilizer had the lowest stomatal conductance activity in both seasons (Table 2).

The different effect of N forms on photosynthesis is associated with stomatal conductance [15]. Differences in photosynthetic characteristics are related to light environment, leaf anatomy, physiology and nutrient status of the leaves. Muhammad et al. [16] found that stomatal conductance is significantly ($P < 0.05$) affected by N forms supplied to the plants. Stomatal conductance was maximum (0.21 mmol $m^{-2}s^{-1}$) in the plants fed with NH_4^+ and minimum (0.13 mmol $m^{-2}s^{-1}$) with the plants fed with NO_3^-. Stomatal conductance was statistically similar in the plants fed with urea and both forms of N (NH_4^+-NO_3). The differences in stomatal conductance of the plants fed with NO_3^- and both forms of N (NH_4^+-NO_3^-) were also statistically similar. However, stomatal conductance of the plants fed with only NH_4^+ was statistically higher than the plants fed with all other forms of N. Stomatal conductance is higher in the plants fed with NH_4^+ than those fed with other forms of N which was in agreement with the results reported by Zhou et al. [14] who recorded higher stomatal conductance in rice plants fed with NH_4+ compared with other forms of N.

3.3 Photosynthetic Rate

The highest photosynthetic rate was recorded in the month of July during the wet season under the sheep manure at 60 kg N/ha with no consistent pattern drawn. Negative photosynthetic rates were recorded in the dry season especially in the month of December and February (Table 3). However, it was observed that no application of fertilizer led to the lowest photosynthetic rates in tea in both seasons in all the three months of the study.

Plant growth and development is frequently dependent on photosynthesis, as this is the process through which all living green plants produce their own food. It is clear that photosynthetic capacity is the basis of agricultural yield and leaf photosynthesis

Table 1. The influence of organic and organomineral fertilizer on the transpiration rate g m−2 s−1 during the wet and dry season

	Dry season			Wet season		
Treatments	**December**	**January**	**February**	**June**	**July**	**August**
0 kg N/ha	0.51c	2.48a	0.09c	0.11b	0.12a	0.01b
Sheep manure 60 kg N/ha	1.51b	4.71a	0.74b	0.33b	0.45a	0.01b
Sheep manure 120 kg N/ha	1.63b	5.74a	0.34bc	1.26a	1.49a	0.10b
Sheep manure 180 kg N/ha	2.70a	4.23a	0.42bc	0.05b	0.64a	0.01b
Sheep manure 240 kg N/ha	1.60b	3.82a	1.65a	1.03a	0.35a	0.13b
4 sheep manure:1 DAP at 60 kg N/ha	2.15ab	4.92a	0.12c	0.16b	0.57a	0.13b
4 sheep manure:1 DAP at 120 kg N/ha	1.26b	4.06a	1.24a	0.85ab	1.07a	0.10b
4 sheep manure:1 DAP at 180 kg N/ha	1.63b	5.41a	0.12c	0.19b	0.41a	0.08b
4 sheep manure:1 DAP at 240 kg N/ha	3.09a	4.56a	0.93b	0.91ab	0.78a	0.09b
8 sheep manure:1 DAP at 60 kg N/ha	2.95a	3.83a	0.59b	0.79ab	0.38a	0.35a
8 sheep manure:1 DAP at 120 kg N/ha	1.76b	4.62a	0.89b	0.01b	0.59a	0.13b
8 sheep manure:1 DAP at 180 kg N/ha	3.42a	4.23a	0.41bc	0.41b	0.22a	0.12b
8 sheep manure:1 DAP at 240 kg N/ha	2.09ab	5.6a	0.55b	0.47b	0.55a	0.04b
NPK 180 Kg/ha	2.55ab	4.01a	1.16ab	0.53b	0.52a	0.13b
P-Value	0.004	0.152	0.021	0.007	0.323	0.048
LSD	1.16	2.485	0.671	0.822	1.035	0.358

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-weeks after sowing accounts for the majority of the variation in biomass production and yield [17]. Photosynthesis is the primary physiological process that is affected by changes in growing conditions, where application of fertilizer significantly increased photosynthesis compared to the control in this study. A lack of fertilizer can disturb photosynthetic activities directly and can also restrict partitioning of assimilates to the fruits from the leaves [18] corroborating the findings of the current study. However, contradictory relationships between leaf photosynthesis and crop yield have been found: positive [19] and negative [20]. Lawlor [21] showed that these contradictory results could be explained by the fact that limiting environmental and plant factors interact strongly to regulate photosynthesis and yield. In a study by Muhammad et al. [16], it was found that Nitrogen forms supplied to the maize plants significantly ($P<0.05$) affected photosynthetic rate as concurrently found in the current study.

Table 2. The influence of organic and organomineral fertilizer on the stomatal conductance (mmol $m^{-2}s^{-1}$) during the wet and dry season

	Wet season			Dry season		
	June	July	August	December	January	February
0 kg N/ha	6.58d	6.50b	1.3b	0.7a	4.8b	0.1a
Sheep manure 60 kg N/ha	8.5d	16.62b	4.4b	1.1a	9.5b	0.2a
Sheep manure 120 kg N/ha	10.5d	28.99ab	2.5b	11.4a	19.4a	0.3a
Sheep manure 180 kg N/ha	30.4a	15.16b	2.6b	1.0a	8.4b	0.3a
Sheep manure 240 kg N/ha	11.3d	12.20b	13.3a	4.0a	7.9b	0.5a
4 sheep manure:1 DAP at 60 kg N/ha	16.8c	8.67b	1.2b	1.3a	8.1b	0.8a
4 sheep manure:1 DAP at 120 kg N/ha	7.1d	8.59b	10.3a	4.9a	15.2a	2.33a
4 sheep manure:1 DAP at 180 kg N/ha	8.2d	26.87ab	1.0b	1.4a	5.3b	0.6a
4 sheep manure:1 DAP at 240 kg N/ha	18.3bc	24.63b	6.2ab	4.8a	13.0ab	0.6a
8 sheep manure:1 DAP at 60 kg N/ha	23.7b	22.41b	7.1ab	10.1a	3.7b	0.6a
8 sheep manure:1 DAP at 120 kg N/ha	11.3d	35.70ab	9.3a	1.0a	6.9b	0.6a
8 sheep manure:1 DAP at 180 kg N/ha	34.9a	50.0a	3.8b	4.5a	2.0b	0.7a
8 sheep manure:1 DAP at 240 kg N/ha	20.5a	10.53b	6.6ab	3.4a	5.5b	0.7a
NPK 180 Kg/ha	19.1bc	29.01ab	9.5a	2.7a	6.0b	2.33a
P-Value	0.035	0.001	0.04	0.211	0.021	0.423

Means followed by different letters in a column are significantly different at 95% confidence level, WAS-weeks after sowing

Table 3. The influence of organic and organomineral fertilizer on the photosynthetic rate (µmol m^{-2} s^{-1}) during the wet and dry season

	Wet Season			Dry Season		
	June	July	August	December	January	February
0 kg N/ha	4.07b	8.7b	-6.6b	-2.9a	13.6a	-3.07a
Sheep manure 60kg N/ha	8.67a	45.7a	1.7a	-2.3a	7.7b	-3.83a
Sheep manure 120 kg N/ha	4.93b	13.8b	13.3a	-0.4a	10.8ab	-0.47a
Sheep manure 180 kg N/ha	8.27a	33.2a	5.0a	-0.7a	7.3b	-0.03a
Sheep manure 240kg N/ha	6.23ab	35.5a	3.5a	0.7a	5.3b	2.77a
4 sheep manure:1 DAP at 60kg N/ha	5.63b	10.5b	9.3a	4.8a	10.3ab	-0.57a
4 sheep manure:1 DAP at 120kg N/ha	7.6a	14.2b	11.7a	7.1a	1.8b	0.2ab
4 sheep manure:1 DAP at 180kg N/ha	5.67b	17.6b	4.7a	-0.4a	0.8b	-2.03a
4 sheep manure:1 DAP at 240kg N/ha	4.57b	12.5b	5.2a	0.7a	4.1b	-5.27a
8 sheep manure:1 DAP at 60kg N/ha	8.67a	21.3ab	8.3a	3.4a	6.9b	3.2a
8 sheep manure:1 DAP at 120kg N/ha	5.90b	10.7b	1.2a	-0.8a	2.5b	-0.1a
8 sheep manure:1 DAP at 180kg N/ha	6.40ab	21.0ab	10.2a	0.9a	0.2b	-0.83a
8 sheep manure:1 DAP at 240kg N/ha	7.87a	25.7ab	14.7a	-0.1a	5.2b	-3.0a
NPK 180 Kg/ha	7.15a	22.5ab	11.5a	2a	4.5b	-1.2a
P-Value	0.164	0.001	0.031	0.432	0.03	0.425
LSD	2.754	18.76	14.42	5.55	9.6	4.29

Means followed by different letters in a column are significantly different at 95% confidence level

4. CONCLUSION

The stomatal conductance and photosynthetic rate were lower during dry season as compared to wet season. The lower stomatal conductance may be attributed to stomata closure to counter water stress. The decrease in photosynthetic rate is due to lower amount of soil water. The high transpiration rate during dry season was attributed to higher vapor pressure deficit. It is therefore recommended that soil amendments should be mixed with inorganic fertilizers to enhance plant physiological processes at a ratio of 8:1 (enriched sheep manure at a ratio of 8 organics: DAP at a rate of 180 kg N/ha) could be used in tea to increase yields as well as maintaining the soils.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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