International Journal of Plant & Soil Science

Volume 35, Issue 23, Page 328-337, 2023; Article no.IJPSS.110712
ISSN: 2320-7035

Effects of Organic and Inorganic Fertilizer on the Population Dynamics of Soil Microorganisms in Tea Rhizosphere at Kericho, Kenya

Caroline C. Mutai [a,b*], Lizzy A. Mwamburi [a] and Pixley K. Kipsumbai [a]

[a] Department of Biological Sciences, University of Eldoret. P.O Box 1125-30100, Eldoret, Kenya.
[b] Tea Research Institute, P.O Box 820 – 20200, Kericho, Kenya.

Authors' contributions

This work was carried out in collaboration among all authors. All authors were involved actively in the research and manuscript development. Author CCM was involved in the development, experimental set-up, data collection, analysis and manuscript. Mwamburi was involved in development, experimental design and manuscript writing. Author PKK contributed in experimental design, data collection, analysis, manuscript writing and editing. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i234247

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/110712

Original Research Article

Received: 15/10/2023
Accepted: 19/12/2023
Published: 21/12/2023

ABSTRACT

Aim: The long-term cultivation of tea (*Camellia sinensis L.*) alters microorganism communities in the rhizosphere; it can increase saprotrophs, pathogenic microorganisms and reduce symbiotrophs. Fertilizers are sources of plant essential nutrients and can influence the activity and population of soil microorganisms. This study aimed to determine the effect of fertilization regimes on the population dynamics of soil microorganisms in the tea rhizosphere for its management.

**Corresponding author: E-mail: carochepmut@yahoo.com;*

Place and Duration: The study was carried out at the Tea Research Institute, Kericho, Kenya during the dry (February-March) and wet season (June-July).
Methodology: Two main fertilizer types; organic (Phymix) and inorganic (Nitrogen, Phosphorus and Potassium- NPK) and foliar fertilizer (Tecamin Max, Tecnokel Amino Mix) as sub treatments application at the rate of 0, 75 and 150 kg N ha^{-1}), were applied in four replications. Sampling of soil was done before treatment application, during the dry season (February-March) and the wet season (June-July). The fungal and bacterial populations for both seasons were characterized. The data collected was analyzed using SAS (version 9) Statistical Software.
Results: The study showed that the fungal colony units varied significantly (P≤0.05) between the types of fertilizer both during dry and rainy season. The interactions of fertilizer type and rate also varied significantly (P≤0.05) for fungal populations during both seasons. No significant variation was noted for the bacterial population (cfu) for both seasons regardless of fertilizer type and rates. The fungi identified included; *Cylindrocarpon* spp., *Trichoderma* spp., *Penicillium* spp., *Aspergillus* spp. *Colletotrichum* spp., *Pestalotiopsis* spp., and *Fusarium* spp. The bacteria included; *Pseudomonas* spp., *Bacillus* spp., *Rhizobium* spp., and *Xanthomonas* spp.
Conclusion: Organic fertilizer increased fungal populations significantly, an indication of enhanced soil health and may be recommended for use.

Keywords: Bacterial and fungal populations; interaction; nutrients; seasons; variations.

1. INTRODUCTION

Soil microorganisms are vital in healthy plant development, protection, nutrient recycling and decomposition of organic matter [1,2]. They also play a vital role in maintenance of the soil structure in agro-ecosystems [3]. Soil physiochemical properties on fertilization can drive changes in microbial communities, structure and metabolic functions [4]. Microbial diversity and biomass are responsive to changes in soil physiochemical properties and management and are useful in predicting changes in soil functions [5]. Studies on the composition and diversity of microbial communities under fertilized soils would be beneficial for effective improvement of soil fertility and productivity in ensuring sustainable development of soil ecosystem and perhaps management of soil pathogenic microbes [6].

The perennial nature of tea crop growth requires continuous fertilization using both inorganic and organic fertilizer, which may alter the pH levels of the soils. Inorganic chemical-based fertilizers have been applied over the years in an attempt to increase soil fertility and tea productivity [7]. However, continuous application of inorganic fertilizer in tea farms acidifies the soils, inflict nutritional imbalance and deterioration of the rhizosphere micro-ecological environment [8]. Similarly, the acidic soils suitable for tea cultivation are also suitable for the growth and development of fungi including pathogenic fungi. The usage organic fertilizers could possibly alleviate soil acidification, have a positive influence on reducing pollution, offer natural and safer sources of plant essential nutrients and can influence the activity and population of soil microorganisms including pathogens in the rhizosphere [9]. They have great potential in mitigating against problems associated with inorganic fertilizers and reduce the need for repeated application to maintain soil fertility.

However, this information about soil microbial diversity and composition in tea plantation with inorganic or organic fertilizer application is limited in Kericho, a major tea producing region in Kenya. The impact caused by application of both inorganic and organic fertilizer on the proliferation of soil pathogens need to be established to recommend on fertilizer regime as contribution to integrated disease management and improved tea productivity. The present study therefore, was performed in an already established field trial to examine the soil pathogenic fungal and bacterial population dynamics and diversity in the soils under three fertilizer regimes of organic (Phymix) and inorganic (the standard NPK 26:5:5) fertilizer on rhizospheric soils at a depth of 0-15cm.

2. MATERIALS AND METHODS

2.1 Study Site

The research was conducted in Tea Research Institute (TRI), Kericho at the Timbilil Estate; located at the East of Kericho town, at Latitude 0°21'48.89"S; Longitude 35°21'39.61"E and altitude of 2178m above the sea level. The area

had a mean annual rainfall of 1800mm and minimum annual mean temperature of 18°C and of a maximum of 23°C. Soil is red volcanic soil that is deep, well-drained with pH range of 5.0-6.5.

2.2 Experimental Treatments and Design

Two fertilizer types; organic used is the Phymix (Phytomeia international; Nairobi, Kenya) and inorganic (NPK 26:5:5) were used as main factor A and randomized completely and two foliar fertilizer types namely Tecamin Max and Tecnokel Amino Mix (Agritech fertilizantes; Nairobi, Kenya) as sub-factor B applied in the three rates (equivalent to 0, 75 and 150kgN ha^{-1}) replicated four times (Total plots; (2 x 2 x 3 x 4 reps = 48 plots). Tea cultivar used on the experimental plots was TRFK 11/4 with a spacing of 4mx2m.

2.3 Soil Sampling in the Field

Random sampling was done following a modification of Lin et al., [10] method to collect soils using a sterilized soil auger from the sites marked by Geographical Positioning Sites (GPS), before fertilizer application to establish initial microorganism population and the procedure was again repeated consequently after fertilization. Three tea bushes were randomly selected at each site and the rhizopheric soil (1-5cm around the root) was collected from each bush pooled to form a composite sample. The soil auger was properly sterilized using 5% sodium hypochlorite and rinsed with sterile water and then dried using a sterile cloth before being used to sample soil from different plots. Sampling was done during the rainy season (June-July) and dry season (February-March). Sampling was done twice per season. The soil samples from each plot were mixed and then sieved through a 2mm mesh sieve to remove plant debris and other coarse materials. The soil samples were placed in well-labelled polythene bags and then taken to the laboratory and stored at 4ºC prior to analysis.

2.4 Quantification of Fungal Populations and Characterization

Spread plate method in pre-sterilized Potato dextrose agar (PDA) medium was used to enumerate microbial populations of fungi in the sampled soil as described by Nur, [11]. Ten grams of the sample soil collected was suspended in 90ml of sterile water blanks in 250ml conical flasks. The soil was diluted serially to yield three dilutions. Using a sterile pipette, 1ml of the third dilution (10^{-3}) was plated onto three Petri-dishes containing PDA and spread evenly using a sterile spreader. The PDA plates was then incubated at room temperature (24 ± 2ºC). After incubating for 72 hours the plates were observed and number of fungal colonies counted using a colony counter to estimate colony forming units per gram of the soil (CFU/g) in order to establish the initial fungal population using the formula [12].

$$\text{Number of fungi (cfu)/g soil} = \frac{\text{Number of colonies}}{\text{Amount plated}} \times \text{dilution factor}$$

Subculturing was then done to obtain pure colonies. Preliminary identification of the isolates involved the examination of colony morphology and cultural features such as pigmentation, elevation, shape and growth form of the fungal and confirmed through microscopy from the Riddel slide cultures [13]. Further, the subsequent isolations were done on selective media for the identified fungi to quantify the fungal population dynamics as a result of the applied fertilizer.

2.5 Quantification of Bacterial Populations and Morphological Characterization

For colony growth, 1ml of 10^{-5} serial diluted soil was plated onto three replicate petri- dishes containing pre-sterilized nutrient agar (NA) using sterile pipette and incubated at 35ºC ± 2ºC for 24 hours. After incubation, the number of colonies formed was counted using a colony counter to obtain bacteria colony forming units per gram of the soil. Only plates containing greater than 30 bacterial colonies and less than 300 bacterial colonies in every sample was considered for estimating the number of CFU/g of the soil. Plates containing less than 30 colonies are considered to be too few to count (TFTC) while those containing greater than 300 colonies are considered to be too many to count (TMTC) [14].

The identification of the isolates involved the examination of colony morphology and culture features such as pigmentation, elevation, shape and growth form of safranin-stained bacterial isolates under the dissecting and compound microscope, further microscopy in oil immersion eye piece magnification was used and gram staining. The subsequent isolates were done using selective media of the identified bacterial species.

3. RESULTS

3.1 Effect of Fertilizer on the Diversity of Fungi and Bacteria on Tea Rhizosphere

The composition of the rhizospheric microbial community in tea plants varied though was not significantly different (p≤0.05) depending on the season and the fertilization regime. Results obtained from the first season (February-March) indicated that fungal colony units in the tea rhizosphere varied significantly (P≤0.05) between organic and inorganic fertilizer form applied. Only the organic amendment showed significant (P≤0.05) variation of fungal cfu among the different foliar fertilizers. In addition, both interactions of fertilizer and rate plus foliar and rate also varied significantly (P≤0.05) for fungal populations. There was no significant (P≤0.05) variation in bacterial cfu population for organic amendment and foliar fertilizer but a variation was noted in inorganic (Table 1).

Results during the rainy season showed that, the fungal population varied significantly (P≤0.05) in the organic fertilizer applied into tea rhizosphere than with the fungal population in the inorganic fertilizer applied to rhizosphere. The organic amendment showed significant (P≤0.05) variation of fungal population between the different foliar fertilizers regimes but there was no significant (P≤0.05) variation in inorganic amendment. In addition, both interactions of fertilizer type and rate of foliar also varied significantly (P≤0.05) for fungal populations (Table 2).

There was significant (P≤0.05) variation in bacterial cfu for both organic and inorganic amendment however, a significant variation (P≤0.05) between different foliar fertilizers and rate was recorded as shown in Table 2.

The soil pH in all the sampled plots were within the ideal requirement for tea production (4.5 and 5.6). Organic fertilizer (Phymix) however, increased the soil pH with Tecnokel Amino mix foliar to 5.17 than with the inorganic NPK fertilizer combined with Tecnokel Amino mix foliar (4.41). However, there was no significant differences (P≤ 0.05) in pH between rates and foliar (Table 3).

It was noted that there was a decrease in bacterial population with a lower pH at the rate of 75kg N ha-1 in organic fertilizer (Tecnokel amino mix) with a mean of 24 cfu/g while inorganic (Tecnokel amino mix) with a mean of 74 cfu/g, while the population of fungi increased in the organic (Tecamin foliar) with a mean of 42.5cfu/g.

3.2 Morphological Characterization of Fungi

From the tea rhizospheric soil, eight fungal genera were isolated (Table 4). Among the fungal genera identified included the *Trichoderma* sp. which was characterized by the initial white colour which turned bright green with rapid growth and branching in PDA medium (Plate 1). *Pestaloti*a spp. had a slow-growth with cottony, white to grayish colonies with a velvety and powdery texture but on maturity the colonies darkened. Under the microscope, light-coloured spores were observed (Plate 2).

Penicillium spp., grew rapidly with characteristic blue-green and green spores with a velvety or fluffy appearance in PDA. *Aspergillus* spp. had characteristic conidial heads, green others yellow in colour with a fluffy or velvety appearance. *Colletotrichum* spp. was a fast-grower with cottony white to light grayish colonies. The culture turned brown and black as it matured. *Fusarium* spp. had white to purple colonies with a cottony or fluffy texture with prominent macroconidia in PDA (Plate 3). *Cylindrocarpon* spp. formed a flat, spreading colony with a white to grayish colour which turned darker as it matured and developed a velvety texture. It produced black and dark brown conidiospores (Plate 4), and *Beauverria bassiana* was characterized by the white colour with aseptate branched mycelium and roundish oval conidiospores when observed under the microscope from Riddel slide cultures.

3.3 Morphological Characterization of Bacteria

Some common bacteria that were found in the tea rhizosphere included *Pseudomonas* spp., *Bacillus* spp., *Bacillus mycoides, Rhizobium* spp., and *Xanthomonas* spp. (Table 4). *Pseudomonas* spp. was noted by the single polar flagellum, aero-bacillus shape and gram-negative nature. There was several *Bacillus* spp. (Plate 5 and 7), however *Bacillus mycoides* was conspicuously prominent. *Rhizobium* spp. exhibited the rod-shaped morphology and their characteristic pale pink to whitish colour. *Xanthomonas* spp. was characterized by their aerobic property, short rods and gram negative.

Table 1. The effect of different types and rates of fertilizer on fungal and bacterial population during the dry season (February- March)

Fertilizer type	Foliar type	Fungi (cfug-1 soil) x10^3		Bacteria (cfug-1 soil) x10^5	
		75kg N ha-1	150kg N ha-1	75kg N ha-1	150kg N ha-1
Organic (Phymix)	Tecamin Mix	19.5±2.56	26.8±3.35	31.3±6.6	32.3±3.19
	Tecnokel Amino Mix	12.5±1.04	26±2.16	36.5±3.3	33.8±11.15
	Control (0)	10±1.08	11±1.08	29.5±3.97	25.8±1.99
P=0.05		0.01	0.10	0.68	0.68
CV (%)		21.4	28.4	44	44
Inorganic (NPK)	Tecamin Mix	29.5±5.55	24±3.16	31.5±3.85	23.8±3.46
	Tecnokel Amino Mix	24±1.78	15±2.8	37±6.82	45.8±5.44
	Control (0)	14±1.58	25±2.08	39.8±6.66	34±4.66
P=0.05		0.05	0.10	0.68	0.04
CV (%)		22.1	28.5	35	27.3

Table 2. The effect of different types and rates of fertilizer on fungal and bacterial population during the wet season (June-July)

Fertilizer type	Foliar type	Fungi (cfug-1 soil) x10^3		Bacteria (cfug-1 soil) x10^5	
		75kg N ha-1	150kg N ha-1	75kg N ha-1	150kg N ha-1
Organic (Phymix)	Tecamin Mix	42.5±2.75	31.2±3.50	47.8±6.08	28.8±3.52
	Tecnokel Amino Mix	34.8±4.07	34.0±3.29	74.5±3.3	38.3±2.60
	Control (0)	21.2±3.12	33.7±1.65	30.7±1.49	33.7±2.10
P=0.05		0.02	0.74	0.002	0.05
CV (%)		22.1	16.4	19	12.5
Inorganic (NPK)	Tecamin Mix	17.5±4.29	23.5±3.23	25.8±2.66	60.3±1.55
	Tecnokel Amino Mix	16.8±1.79	17.5±1.71	24.0±1.87	66.0±2.16
	Control (0)	12.3±0.85	27.5±2.63	27.8±4.01	28.8±3.12
P=0.05		0.49	0.05	0.74	0.0001
CV (%)		40.7	20.1	26	8

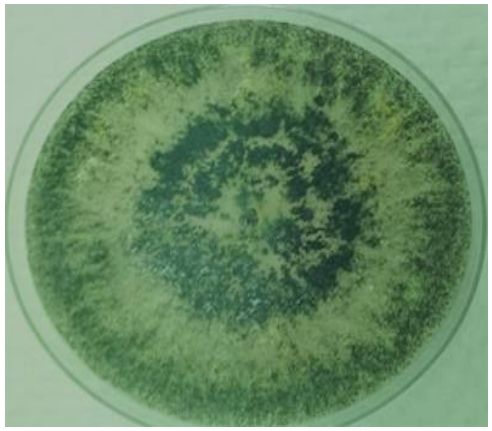

Plate 1. Trichoderma culture on PDA

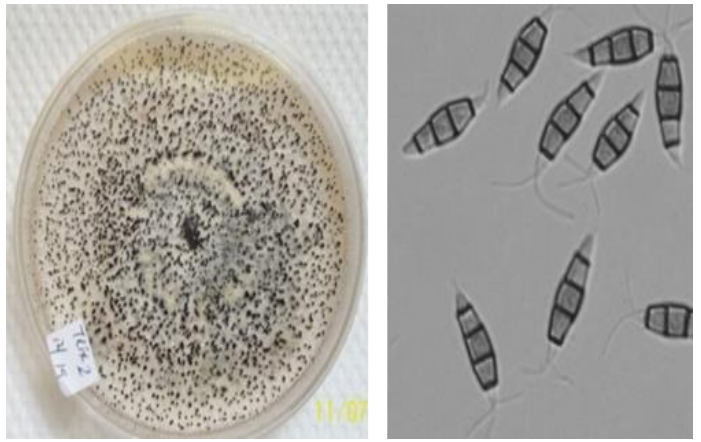

Plate 2. Pestalotia culture and conidia

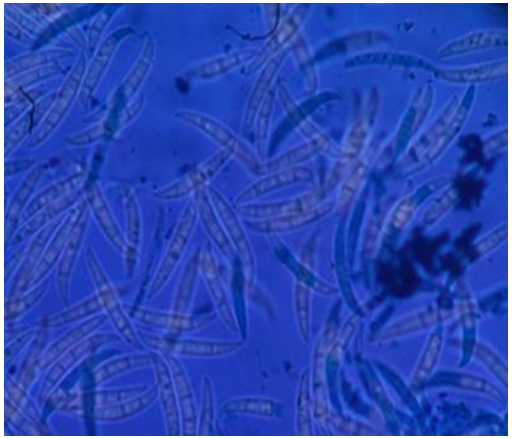

Plate 3. Macroconidia of *Fusarium* spp.

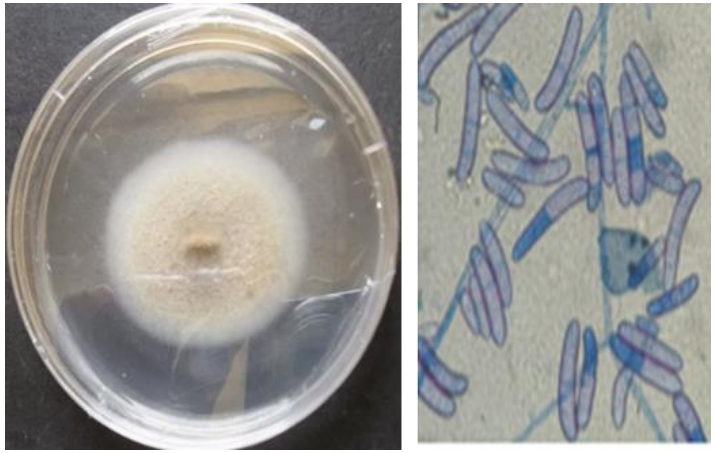

Plate 4. Cylindrocarpon culture and spores

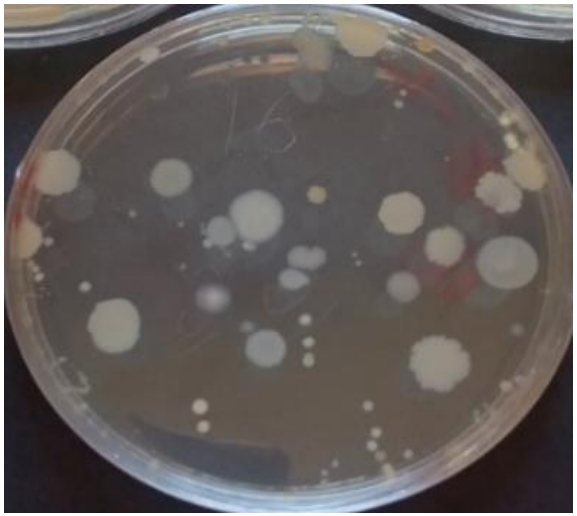

Plate 5. Bacterial culture on Nutrient Agar media

Plate 6. Streaked cultures of bacterial isolates

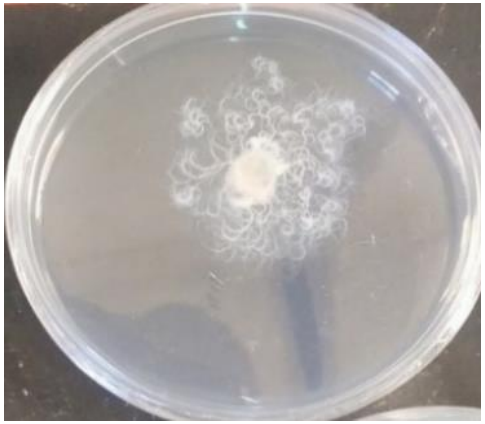

Plate 7. Colonies of *Bacillus mycoides*

Table 3. The effect of different types and rates of fertilizer treatments on the soil pH

Fertilizer type	Foliar type	Fertilizer rates	
		75kg N ha-1	150kg N ha-1
Organic (Phymix)	Tecamin Mix	4.16±0.3	3.86±0.04
	Tecnokel Amino Mix	5.17±0.2	4.37±0.2
	Control (0)	4.52±0.5	4.65±0.4
P=0.05		0.08	0.05
CV (%)		11.3	8
Inorganic (NPK)	Tecamin Mix	4.56±0.1	4.66±0.3
	Tecnokel Amino Mix	4.415±0.1	4.728±0.3
	Control (0)	4.85±0.2	4.67±0.3
P=0.05		0.04	0.96
CV (%)		3.93	7.65

Table 4. Microorganisms isolated from the treated tea rhizospheric soils

Fungal genera and species	Bacterial genera and species
Trichoderma spp.	*Pseudomonas* spp.
Pestalotia spp.	*Bacillus* spp.
Beauveria bassiana	*Bacillus mycoides*
Cylindrocarpon spp.	*Rhizobium* spp.
Penicillium spp.	*Xanthomonas* spp.
Apergillus spp.	
Colletotrichum spp.	
Fusarium spp.	

4. DISCUSSION

The application of fertilizer in the tea fields is a common practice to maximize yields and to replenish the nutrients lost through harvesting. Excessive chemical fertilizer though has resulted to numerous effects such as nitrogen leaching, soil degradation, soil compaction, reduction in organic matter, loss of soil carbon and micro-organisms activity. Though both organic fertilizers provide similar nutrient elements as inorganic fertilizer, the effect on rhizospheric micro-oganisms vary significantly, results have indicated that there is a rise in soil acidity with frequent use of nitrogenous fertilizer [15]. There are many different types of fungi and bacteria that can be found in the rhizosphere of tea plants, and the specific diversity may depend on factors such as soil type, climate, and management practices. Both fungi and bacteria are important components of the rhizospheric microbial community in tea plants, and their interactions with the tea plant can have significant impacts on plant growth, yield and quality (9). Additionally, results indicated that organic fertilizer treatment improved soil pH. The current study established that the use of organic fertilizer significantly increased the bacterial population during the wet season. This data is in agreement with previous findings that NPK chemical fertilizer caused a significant decrease in bacterial populations [16].

There were significant differences in the soil fungi and bacteria composition observed in the tea rhizosphere with organic fertilizer and inorganic fertilizer. Comparable results were observed by Lin *et al*., [10], with long-term continuous cropping of tea fungal population increased significantly in soils where inorganic fertilizer was applied, because fungi are acidophilic and are capable of flourishing in an acidic environment [17]. The study has further shown that the application of chemical fertilizers decreased the soil pH, which further stimulated the increase of fungi. However, application of organic fertilizer was able to increase this effect. Organic fertilizers act as an effective source of energy for soil microbes that improve soil structure and plants growth and development [18], this could explain the observation in this study. Zhang et al*.*, [19] have documented the progressive soil-plant response potential benefits from organic fertilizer showing a rise in microbial activities enhancing crop growth and restraining pest and diseases.

The number of fungi was found to increase in the soils applied with inorganic fertilizer. Lin et al., [10] described tea as a unique crop, because the

soil becomes strongly acidified following its planting. The tea plant itself acidifies soil which is then, compounded by the fertilizers being applied during management [8]. The combined effect on lowering the soil pH tend to favour fungal growth, but the soil become unsuitable for bacterial growth. However, with the application of organic fertilizer the soil pH increased thence becomes suitable for bacteria and their ecological functions as corroborated by the study of Aziz et al., [20].

There were significant differences in the soil fungi and bacteria composition observed in the tea rhizosphere with organic fertilizer and inorganic fertilizer. Among the microorganisms identified in the rhizosphere of tea plants included *Cylindrocarpon* spp., *Trichoderma* spp., *Penicillium* spp., *Aspergillus* spp. *Colletotrichum* spp., *Pestalotiopsis* spp. and *Fusarium* spp. which corroborated the works of Chen et al., [21]. The bacteria that were found in the tea rhizosphere included *Pseudomonas* spp., *Bacillus* spp., *Rhizobium* spp. and *Xanthomonas* spp. which was comparable to results by Lin et al., [10] and Mandic-Mulec & Prosser [22].

5. CONCLUSION

Organic fertilizer enhanced fungal and bacterial populations in rhizospheric soil during wet season. It was noted that soil pH was related to fertilizer treatment in that organic treatments increased the soil pH compared to inorganic treated plots. These findings therefore, suggested that fertilizer can shape microbial composition and population into the tea rhizosphere. This study provides a promising strategy to soil health by application of organic fertilizers as opposed to inorganic fertilizer, though was found to favour fungi.

ACKNOWLEDGEMENTS

The authors are thankful to the Tea Research Institute, Kericho for allowing the research to be undertaken in the tea experimental plots. Similar gratitude is also to the Laboratory technologists of the Tea Research Institute.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Santos LF, Olivares FL. Plant microbiome structure and benefits for sustainable agriculture. Curr Plant Biol. 2021;26: 100198. DOI:10.1016/j.cpb.2021.100198.
2. Shah KK, Tripathi S, Tiwari I, Shrestha J, Modi B, Paudel N, Das BD. Role of soil microbes in sustainable crop production and soil health. A review. Agricultural Science and Technology. 2021;13(2):109-118.
3. Prasad S, Malav LC, Choudhary J, Kannojiya S, Kundu M, Kumar S, Yadav AN. Soil microbiomes for healthy nutrient recycling. In Current trends in microbial biotechnology for sustainable agriculture springer, Singapore. 2021;1-21.
4. Han J, Dong Y, Zhang M. Chemical fertilizer reduction with organic fertilizer effectively improves soil fertility and microbial community from newly cultivated land in the Loess Plateau of China. Applied Soil Ecology. 2021;165:103966.
5. Jacoby R, Peukert M, Succurro A, Koprivova A, Kopriva S. The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions. Frontiers in Plant Science. 2017;8:1617.
6. Kughur PG, Otene V, Audu OC. Effects of intensive agricultural production on the environment in benue state, Nigeria. IOSR J Agric Vet Sci. 2015;(8):7–11. DOI:10.9790/2380-08810711.
7. Adesemoye AO, Kloepper JW. Plant–microbes interactions in enhanced fertilizer-use efficiency. Applied microbiology and biotechnology. 2009; 85:1-12.
8. Le VS, Hermann L, Hudek L, Nguyen TB, Brau L, Lesuer D. How application of agricultural waste can enhance soil health in soils acidified by tea cultivation. A review. Environ. Chem. Lett. 2022;20: 813-839. DOI: 10.1007/s10311-021-01313-9.
9. Kamunya S, Ochanda S, Cheramgoi E, Chalo R, Sitienei K, Muku O, Bore JK. Tea growers guide, Kenya; 2019.
10. Lin W, Lin M, Zhou H, Wu H, Li Z, Lin W. The effects of chemical and organic fertilizer usage on rhizosphere soil in tea orchards. PloS one. 2019;14(5):017-018.
11. Nur MMZ, Rosli BM, Kamaruzaman S, Md MM, Yahya A. Effects of selected herbicides on soil microbial populations in oil palm plantation of Malaysia. A microcosm experiment. African Journal of Microbiology Research. 2013;7(5): 367-374.

12. Roberts S, Danmalidoi Y, Bicksler A. Soil microorganisms. What they do and how to measure them. ECHO Asia notes; 2016. AN Issue #27 (/en/resources/d0eaf359-b4a443a1801bab1320c1ba76).
13. Riddel RW. Permanent stained mycological preparation obtained by slide culture. Mycologia. 1950;42:265-270.
14. Sieuwerts S, De Bok FA, Hugenholtz J, van HylckamaVlieg JE. Unraveling microbial interactions in food fermentations. from classical to genomics approaches. Applied and environmental microbiology, 2008;74(16):4997-5007.
15. Owuor PO, Omwoyo WN, Ongeri DM, Kamau DM. Effects of nitrogenous fertilizer rates, plucking intervals and location of production on the micronutrient levels of clonal black tea. International Journal of Tea Science. 2014;10(01,02):25-33.
16. Sun R, Zhang XX, Guo X, Wang D, Chu H. Bacterial diversity in soils subjected to long-term chemical fertilization can be more stably maintained with the addition of livestock manure than wheat straw. Soil Biology and Biochemistry, 2015;88:9-18.
17. Yang WC, Li C, Wang S, Zhou B, Mao Y, Rensin C, et al. Influence of biochar and biochar- based fertilizer on yield, quality of tea and microbial community in an acid tea orchard soil. Appl Soil Ecol. 2021;166: 104005
DOI: 10.1016/j.apsoil.2021.104005.
18. Shaji H, Chandran V, Mathew L. Organic fertilizers as a route to controlled release of nutrients. In Controlled release fertilizers for sustainable agriculture, Academic press. 2021;231-245.
19. Zhang QC, Shamsi IH, Xu DT, Wang GH, Lin XY, Jilani G, Chaudhry AN. Chemical fertilizer and organic manure inputs in soil exhibit a vice versa pattern of microbial community structure. Applied Soil Ecology, 2012;57:1-8.
20. Aziz U, Rehmani MS, Wang L, Luo X, Xian B, Wei S, Shu K. Toward a molecular understanding of rhizosphere, phyllos-phere, and spermosphere interactions in plant growth and stress response. Critical Reviews in Plant Sciences. 2021;40(6): 479-500.
21. Chen Y, Fu W, Xiao H, Zhai Y, Luo Y, Wang Y, Liu Z, Li Q, Huang J. A Review on rhizosphere microbiota of tea plant (*Camellia sinensis* L): Recent Insights and future perspectives. Journal of agricultural and food chemistry; 2023.
DOI:10.1021/acs.jafc.3c02423.
Advance online publication.
Available:https://doi.org/10.1021/acs.jafc.3c02423.
22. Mandic-Mulec I, Prosser JI. Diversity of endospore-forming bacteria in soil. characterization and driving mechanisms. In Endospore-forming soil bacteria . Berlin, Heidelberg: Springer Berlin Heidelberg. 2011;31-59.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/110712