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IMPACT OF LAND USE ON DISTRIBUTION AND DIVERSITY OF *Fusarium* species IN TAITA TAVETA, KENYA

[IMPACTO DEL USO DEL SUELO SOBRE LA DISTRIBUCIÓN Y DIVERSIDAD DE *Fusarium* spp. EN TAITA TAVETA, KENIA]

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SUMMARY

The effect of Land Use Types (LUTs) on distribution and diversity of *Fusarium* species in soil were evaluated in Taita Taveta district, Kenya. Soil samples were collected from sixty points across a land use gradient covering six different LUTs, at 0 to 10 and 10 to 20 cm soil depths. Using *Fusarium*-selective media, a total of 1865 *Fusarium* isolates were recovered from the soil samples which resulted into 26 *Fusarium* species with *Fusarium oxysporum* and *Fusarium solani* being the dominant species in this area. Difference in *Fusarium* abundance, diversity and richness across the LUTs was significant (P<0.001) with horticulture being the richest and the most diverse LUT. The top soil layer had significantly higher *Fusarium* abundance and richness (P<0.05). A Principal Component Analysis (PCA) based on the relative *Fusarium* species abundance differentiated the LUTs with 79.69 %. There were significant positive correlation between P and pH levels with Fusaria abundance, richness and diversity (P<0.001). Abundance and diversity of *Fusarium* was also positively correlated with soil Mg and K (P<0.05). However, a significant negative correlation between exchangeable acidity and abundance (r=-0.605), richness (r=-1.317) and diversity (r=-0.16) was observed (P<0.05). Negative correlation was also observed between Nitrogen and richness (r=-2.94) and diversity (r=-0.67) of *Fusarium* species.

Key words: Land Use Type; *Fusarium* spp.; Soil depth; Soil chemicals.

INTRODUCTION

Fusarium is one of the most ubiquitous, abundant, and important genera of soil microfungi. The genus contains many species of environmental, agricultural and human health importance (Martino *et al*., 1994; Vismer *et al*., 2002). Plant diseases caused by *Fusarium* spp. include vascular wilts, seedling damping-off, and rots of stems, crowns, and roots. Some species of *Fusarium* also produce mycotoxins resulting in food contamination. The predominance of *F. xylarioides*, *F. verticillioides* and *F. graminearum* in Kenyan maize (Kedera *et al.,* 1999) is cause for concern because most isolates of these species produce mycotoxins that can cause equine leucoencephalomalacia, porcine pulmonary edema and experimental liver cancer in rats.

In addition to being strongly plant-pathogenic, some *Fusarium* can also have beneficial attributes. For example, *Fusarium oxysporum,* is one of the most economically destructive species of *Fusarium* (Leslie and Summerell, 2006), and yet has also been reported to increase plant growth (Pung *et al*.,1992) and even to suppress plant disease (Larkin *et al*.,1993). Given the high abundance and ubiquitous distribution of *Fusarium* species in the soil, their role in saprophytic decomposition, especially cellulolytic activity, is a key process in the cycling of nutrients in many terrestrial ecosystems. Trophic-level links between methyltrophic bacteria and *Fusarium* spp. have been revealed (Lueders *et al*., 2004). Following application of ^{13}C methanol to soils, a substantial amount of labeled C was shown to be present in eukaryotic DNA that was dominated by *Fusarium* species.

Some species, in particular *F. oxysporum*, have been found to have an important role in soil denitrification (Laughlin and Stevens, 2002; Takaya *et al*., 2002) having the ability to reduce NO, N_2O and even fully N_2 (Shoun *et al*., 1992). *Fusarium* fungi are therefore a functionally important biological component of terrestrial soils. Land use and management practices affect the distribution of *Fusarium* populations in the soil by changing soil properties. These practices

include soil tillage, addition of agrochemicals, clear-cutting and controlled burning which may affect soil water content,, temperature aeration, pH regimes, organic carbon and nitrogen levels. These are however less well documented and understood (Kasel *et al*., 2008, Miller and Lodge, 1997, Wu, *et al*., 2008). Prevalence of *Fusarium* in Kenya threaten the productivity of major crops, for example, ear rot caused by *F. verticillioides*, decreased yield but more importantly produce mycotoxins that threaten human and animal health. Previous studies in Kenya on *Fusarium* prevalence indicate that the following species are common seed contaminants; *F. graminearum, F. culmorum, F. sporotrichioides, F. poae, F. crookwellense, F. xylarioides, F. verticillioides,* and *F. avenaceum* (Kedera *et al*., 1999). All the *Fusarium* species that infect cereals are capable of surviving saprophytically on crop debris (Parry *et al*., 1995). With three quarters of the country's land being uncultivable, the cultivable lands are under intensive agricultural production and this brings with it the negative effects reported for modern methods of intensified land management practices including increase in pathogenic species of *Fusarium* (Luque *et al*., 2005). Understanding how land use and management practices affect soil *Fusarium* communities will have tangible benefits beyond plant disease control (Wu *et al*., 2008). This study explored the effects of different land use and management practices on distribution and diversity of soil *Fusarium* across land use gradient in Taita Taveta district, Kenya.

MATERIAL AND METHODS

Study Site Description

The study was conducted in Ngangao forest and the adjacent farmlands, in Taita Taveta district, located in Coast province in Kenya. The study area has unique agro-ecological zones that dominantly favour agricultural land use. Ngangao forest has both natural and planted tree plantations. The natural forest consists of a broad diversity of indigenous trees which included; *Strombosia scheffleri, Dicralonepis usambarica, Graibia zimmermanii, Oxyanthus speciosa, Dracaena deremensis, Rauvolvia mannii, Rytiygynia schumanii, Coffea fadenii, Psychotria taitensis, Saintpaulia taitensis,* and *Chassalia discolor*. This forest is unique within Kenya and forms a treasure house of flora and fauna with many species occurring nowhere else in the world (Newmark, 1998; Wass, 1995).

In the adjacent agricultural farmlands, the dominant land use is horticulture and maize based intercropping system. The soils are high-humic A-horizons overlying pinkish acid sandy loam. The soils are mainly haplic acrisols, eutric cambisols, chromic luvisols and regosols. The sandy loams of this area are generally deep with high infiltration rates, a low pH (3 to 5), low water holding capacity are low in nutrients due to excessive leaching. The soils are also characterized by the presence of high aluminum levels, but low calcium levels, causing a low cation exchange capacity.

Soil Sampling

Soil samples were collected across the land use gradient. The sample plots were established at fixed intervals along sample strips, which were at a fixed distance. To avoid auto-correlation the recommended distance between sample plots was 200 m. A total of hundred and ten points were marked. The points had their X and Y coordinates using a GPS 38 Personal Navigator Positioning System. From these, sixty points were selected randomly to represent six major Land Use Types (LUTs) namely; Horticulture, Maize, Fallow/Shrub land, Nappier grass, Planted forests (Pines and Cypress) and Indigenous forests. Soil auger which was 10 cm deep and 6 cm in diameter was used to collect soil samples.

Twelve sub-samples were thoroughly mixed in sterile containers to constitute a composite sample from which 500 g soil was taken, placed in sterile paper bags and labeled. The auger was sterilized by dipping it in 70% ethanol between sampling points and depths to avoid cross contamination. The 0 to 20 cm soil depth was chosen for mycological considerations since it contains the majority of soil microfungi (Skujins, 1984). Samples were placed in a cool box and taken to the laboratory. Soil samples were aseptically air-dried in a laminar flow hood, to prevent microbial activity, for 48 h and then stored at 5 ^{o}C in paper bags until they were processed.

Isolation of *Fusarium* species from soil

Fusarium spp were isolated from soil using serial dilution plating (Burgess *et al*., 1988) with 0.1 % Tap Water Agar (TWA), Brayford (1993). *Fusarium*-selective PCNB-Peptone Agar (PPA) media were used to recover *Fusarium* isolates from the soil. Petri dishes containing media were all stored at 5 ^{o}C for at least 3 days prior to inoculation. The drier media more quickly soaked up excess water in the suspension, which helped to minimize bacterial contamination.

From each of the two levels of soil depth, in each of the sampling point, 10 g of air-dried soil were removed and added to 90 ml of sterile 0.1 % TWA. The mixture was vigorously agitated (200 rpm for 60 s on a Lab-Line Orbital shaker, Melrose Park, IL) and 10 ml of resulting suspension were pipetted into a flask containing 90 ml of sterile distilled water. This

procedure was repeated up to the third ten-fold dilution. Then, 1-ml aliquots from second and third dilutions, in three replicates, were aseptically pipetted on to the petri dishes containing *Fusarium*-selective PPA media and spread evenly across the agar surface with a sterilized bent glass applicator. The Petri dishes were then incubated in an alternating temperature regime, 25 ^{o}C day/ 20 ^{o}C night, at about 65 % relative humidity, under cool white fluorescent lights (Philips TL 40W/80 RS F40BLB) with a 12 h photoperiod for 7 to 10 days. Observations were made from the third day onwards for developing colonies.

Colonies from PPA media were transferred to Synthetic Nutrient Agar (SNA) media. For each of the colonies growing on PPA plates, a well-defined and shaped colony was chosen and a small piece at the edge of the colony was carefully and aseptically transferred onto a separate SNA medium Petri dish and incubated at 25 ^{o}C for 5 days. Subsequently, in order to obtain monosporic cultures of each colony formed on SNA, from which identification was based, very dilute inocula, of 5 to 10 spores per drop of suspension (when viewed at low power magnification), were prepared and spread on 2 % Tap Water Agar plates. These were then incubated for 15 h for germination. Germlings were then subcultured on different media which were SNA, Carnation-Leaf-Agar (CLA) and Potato-Dextrose-Agar (PDA) media plates, for growth and identification. Many species of *Fusarium* readily formed sporodochia with robust, uniform macroconidia on the CLA that were very useful for identification (Leslie and Summerell, 2006). PDA cultures were used to assess pigmentation and gross colony morphology. Cultures grown on SNA were evaluated for microconidia which were more abundant and diverse on this medium, and for chlamydospores, which were more common and produced rapidly on this medium.

All the pure isolates subcultured on PDA, CLA and SNA were incubated for ten to twenty days at 25 ^{o}C under fluorescent lamps. *Fusaria* were identified to the species level where morphological characters were used as the basis of identification (Nelson *et al*., 1983). Identification was made according to Nelson *et al*., (1983), Burgess *et al*., (1988), Brayford (1993) and Leslie and Summerell (2006). After identification, the single spore cultures were stored in agar slants of SNA in screw cap bottles at 4 ^{o}C and in sterilized soil in screw cap bottles using the standard techniques.

Soil pH was determined in distilled water and IN KCl (1:2.5, soil: solution ratio). Total Nitrogen was determined by the catalytic oxidation of organic and chemically combined nitrogen and subsequent alteration to NH_4 by the micro Kjeldahl process. Cation Exchange Capacity (CEC) was determined after a first exchange with 1N ammonium acetate at pH 7, and a second exchange with 1N KCl. Exchangeable Calcium, Magnesium and Potassium were extracted with 1N ammonium acetate, and determined by atomic absorption spectroscopy for Ca and Mg, and by emission spectroscopy for K. Soil P content was analysed by the method of compartmental analysis of the kinetics of isotopic exchange of phosphate ions in soil-solution systems maintained in a steady state. Other variables like Ca, Cu, Fe, Mg, Mn, K, and exchangeable acidity were determined using Mehlich method (Hinga *et al.*, 1980). Total Carbon was estimated by oxidation using sulphuric acid and titrating the unused residue against ferrous sulphate (Nelson and Sommets, 1975).

Statistical Analysis

The data obtained on distribution and diversity of *Fusarium* species in the soil in relation to soil chemicals were analyzed using Biodiversity analysis R package (Kindt and Coe, 2005) and GenStat computer package, discovery edition. Data obtained on abundance were transformed using logarithm so as not to violate normality assumptions. Means found to be significantly different were separated using Tukey test at $P<0.05$.

RESULTS

From the sixty soil sampling points across the six LUTs, 1,865 isolates of *Fusarium* were recovered. The identification of these isolates resulted into 26 *Fusarium* species (Table 1). The most frequently isolated species was *F. oxysporum* (37.9 %) followed by *F. solani* (10%). The two accounted for 47.9 % of all *Fusarium* isolates recovered and they were the only species recovered across the six LUTs. Isolation of *Fusarium* was greatest from maize LUT (51.6 %) followed by horticulture LUT (33.2 %) while the planted forests had the least number of isolates (2.3 %). Maize and horticulture LUTs contributed 84.8 % of all *Fusarium* isolates obtained while both planted and indigenous forests LUTs contributing only 5.9 %.

The diversity of *Fusarium* sp. also varied significantly ($P<0.001$) with LUTs as shown by the Shannon indices in Table 2. Horticulture LUT had the greatest species diversity ($H=1.21$) followed closely by maize LUTs ($H=1.07$). Planted forests had the lowest diversity of *Fusarium* species ($H=0.09$). *Fusarium heterosporum, F. graminearum, F. decemcellulare, F. xylarioides, F. phyllophilum* and *F. verticillioides* were recovered only from maize LUT while *F. compactum* and *F. scirpi* were isolated from fallow/shrub LUT only. An unidentified *Fusarium* sp. was isolated from indigenous forests.

Table 1. Frequency of *Fusarium* species from different Land Use Types in soils of Taita Taveta district, Kenya.

Fusarium species	Overall Proportion (%)	Proportion (%) per Land Use Type					
		Maize	Fallow/ shrub	Nappier	Horticulture	Planted forest	Indigenous forest
F. oxysporum	37.9	36.9	24.4	28.1	42.5	34.4	35.6
F. solani	10.0	13	12.2	28.1	3.3	7.8	9.6
F. sporotrichioides	7.2	0	14.5	0	17.8	9.4	0
F. graminearum	5.9	11.5	0	0	0	0	0
F. avenaceum	5.7	10.5	0	0	0.9	0	0
F. poae	4.8	6.7	0	0	4.2	0	0
F. chlamydosporum	4.5	0	26.7	3.5	8	0	0
F. acuminatum	4.0	0	11.5	0	9.8	0	0
F. xylarioides	3.2	6.1	0	0	0	0	0
F. verticillioides	2.5	4.8	0	0	0	0	0
F. polyphialidicum	2.0	1.5	0	7	0	3.1	26
F. dlamini	2.0	2.9	0	0	1.6	0	0
F. denticulatum	1.8	1.7	0	0	1.5	0	11
F. nygamai	1.3	0.6	0	28.1	0.6	0	0
F. lateritium	1.2	0	0	0	2.1	17.2	0
F. torulosum	1.0	0	0	0	3.1	0	0
F. phyllophilum	0.9	1.7	0	0	0	0	0
F. semitectum	0.7	0	0	5.3	0.6	0	9.6
F. decemcellulare	0.7	1.3	0	0	0	0	0
F. nelsonii	0.6	0.1	0	0	1.8	0	0
F. scirpi	0.5	0	7.6	0	0	0	0
F. redolens	0.4	0	0	0	1.3	0	0
F. heterosporum	0.4	0.8	0	0	0	0	0
F. spp	0.3	0	0	0	0	0	8.2
F. beomiforme	0.3	0	0	0	0.9	0	0
F. compactum	0.2	0	3.1	0	0	0	0
Overall frequency of isolation (%)		51.6	6.5	2.8	33.2	2.3	3.6

Fusarium redolens, *F. beomiforme* and *F. torulosum* were restricted to horticulture LUT while *F. semitectum* isolates were recovered from nappier and horticulture LUTs only. *Fusarium lateritium* isolates were recovered from soils under horticulture and planted forests LUTs while *F. acuminatum* isolates were recovered exclusively from fallow/shrub and horticulture LUTs.

The diversity profiles of soil *Fusarium* shows that horticulture and maize LUTs had higher diversities than the other LUTs with an uneven distribution as shown Fig.2 & 3. The evenness profiles show two distinctive categories in the study area, less disturbed ecosystems with higher evenness and intensively disturbed ecosystems with lower evenness.

Table 2. Effect of Land Use on abundance, richness and diversity of soil *Fusarium* in Taita Taveta district, Kenya.

LUT	Mean log (abundance + 1)	Mean Richness	Mean Shannon index
Indegenous Forest	1.31 ± 0.27	0.92 ± 0.22	0.23 ± 0.08
Planted Forest	1.07 ± 0.31	0.70 ± 0.22	0.09 ± 0.07
Fallow	1.99 ± 0.31	1.56 ± 0.33	0.42 ± 0.12
Napier	1.22 ± 0.29	0.95 ± 0.32	0.27 ± 0.11
Maize	3.2 ± 0.24	4.91 ± 0.82	1.07 ± 0.18
Horticulture	3.11 ± 0.32	5.38 ± 0.90	1.21 ± 0.15
P value	$P<0.001$	$P<0.001$	$P<0.001$

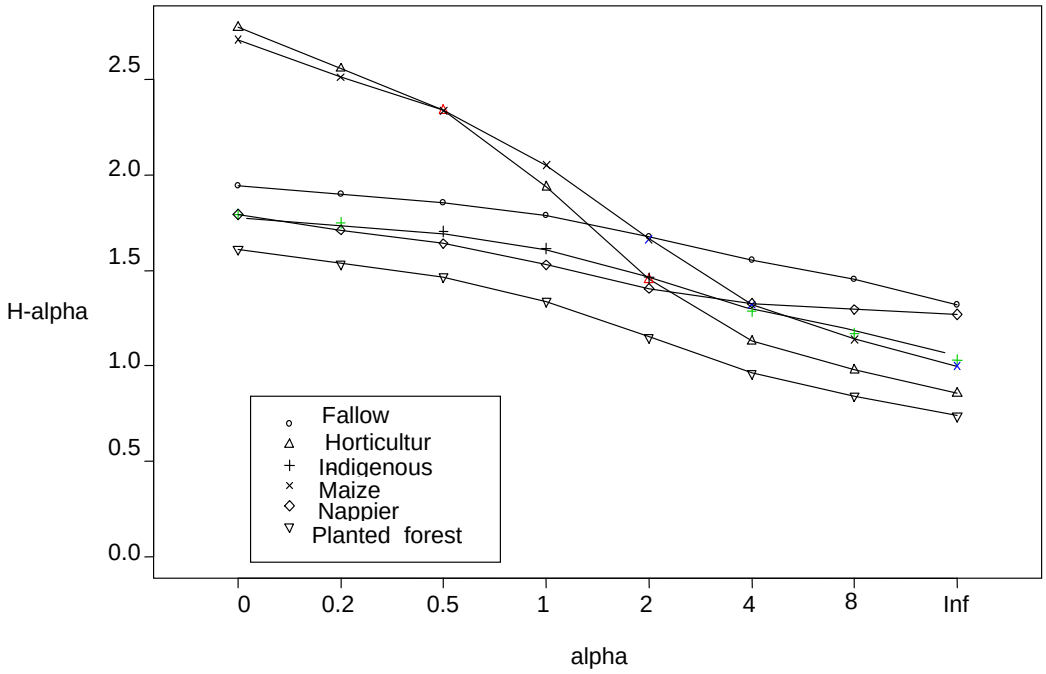

Figure 2. Diversity of *Fusarium* species in different Land Use Types in Taita Taveta district, Kenya.

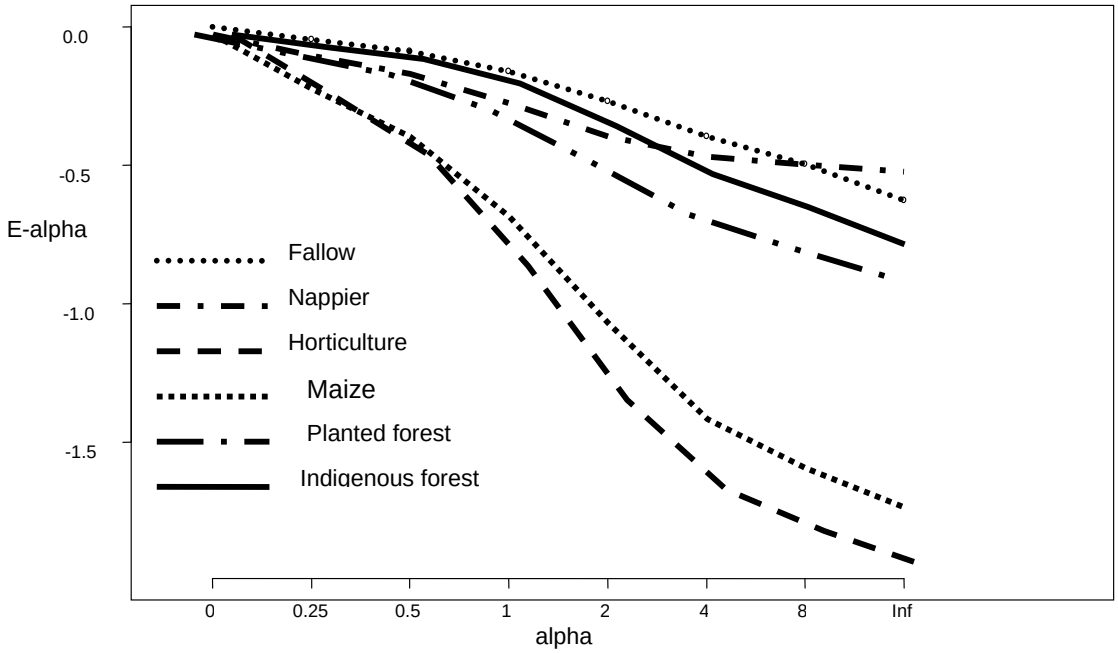

Figure 3. Evenness of *Fusarium* species in different Land Use Types in Taita Taveta district, Kenya

The variation in abundance and richness of *Fusarium* across the six LUTs was found to be highly significant (P<0.001), with maize LUT having the highest abundance followed by horticulture LUT. Planted forests recorded the lowest abundance of *Fusarium*, Table 2. Horticulture was the richest LUT (mean richness of 5.38) followed by maize (mean richness of 4.92). Planted forests scored the least richness value (mean richness of 0.7) as shown in Table 2.

The above results were further confirmed by Principal Component Analysis (PCA) that showed that Factor 1 and 2 explained up to 79.68% of the influence of land use on the distribution of *Fusarium* sp. Factor 1 grouped different isolates of Fusaria into two main sets. The strong pathogens pulled towards maize LUT while the weak pathogens pulled towards horticulture LUT. *Fusarium solani*, *F. graminearum* and *F. poae* pulled towards maize LUT as shown in Figs. 4a and 4b. These are known to be significant pathogens of maize and beans. *Fusarium chlamydosporum*, *F. sporotrichioides*, *F. acuminatum*, *F. semitectum* and *F. nelsonii* are mostly saprophytic and secondary colonists of necrotic or senescent tissues. Factor 2 grouped maize LUT and horticulture LUT on one hand and less disturbed forests and nappier LUT on the other.

The frequency of isolation was greater in the top soil layer than in the lower soil layer. However the difference in diversity observed was not significant (P=0.063), Table 3. The diversity and evenness profiles in Figure 5 and Figure 6, respectively also show that there was no difference in the two parameters with depth.

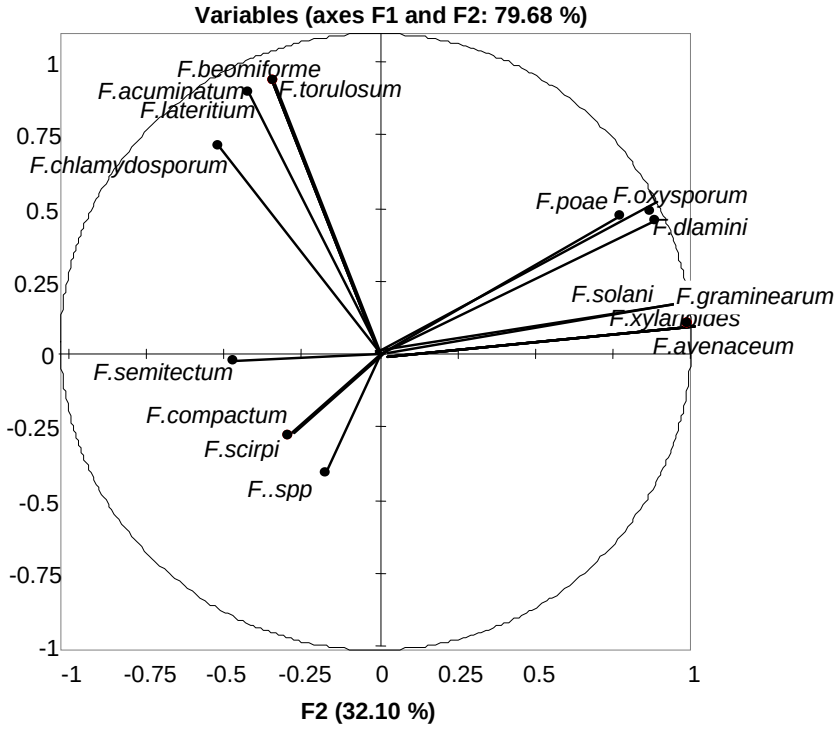

Figure 4a. Relationship between LUTs and different *Fusarium* species in Taita Taveta district, Kenya.

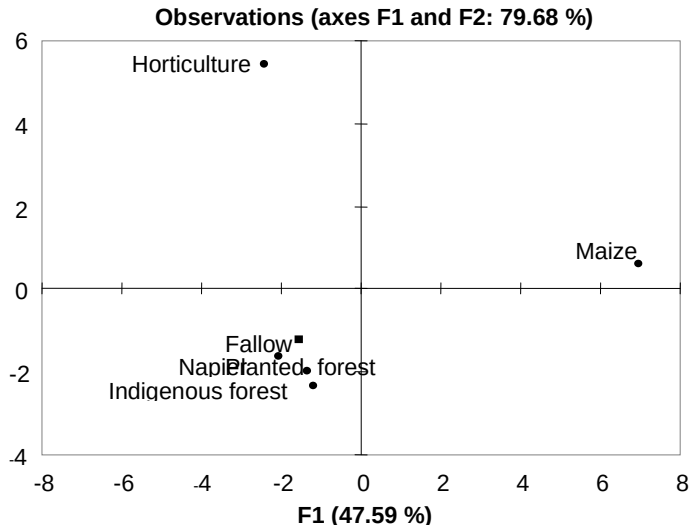

Figure 4b. Relationship between LUTs and different *Fusarium* species in Taita Taveta district, Kenya.

Table 3. Effect of soil depth on abundance, richness and diversity of soil *Fusarium* in Taita Taveta district, Kenya.

Soil Depth Level	n	Mean log (Abundance +1)	Mean Richness	Mean Shannon index
0 – 10 cm	60	2.23 ± 0.21	2.87 ± 0.45	0.65 ± 0.10
10 – 20 cm	60	1.65 ± 0.18	1.75 ± 0.30	0.41 ± 0.08
P value		*P*=0.039	*P*=0.041	*P*=0.063

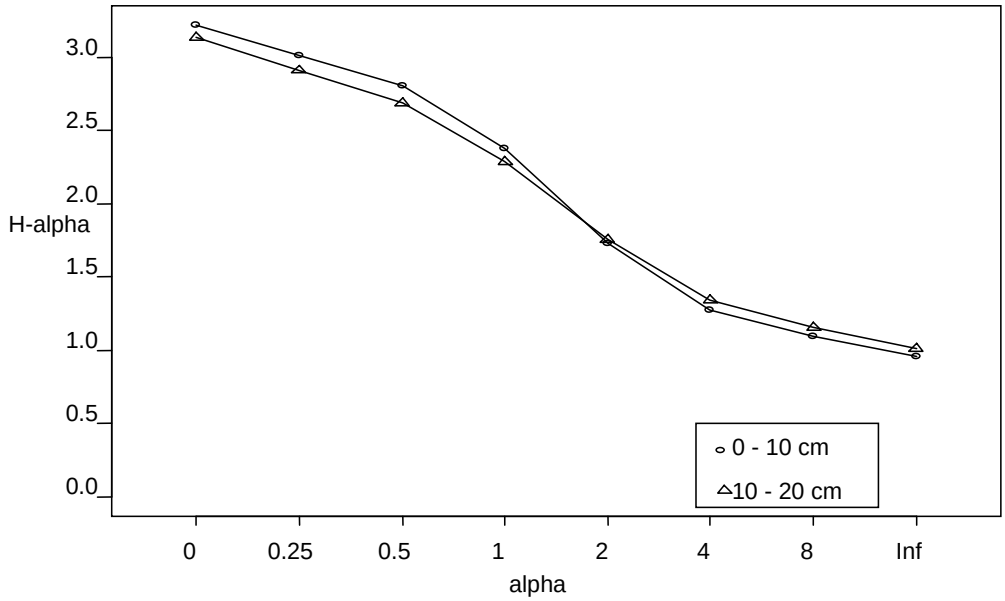

Figure 5**.** Diversity of *Fusarium* species under varying soil depths in Taita Taveta district, Kenya.

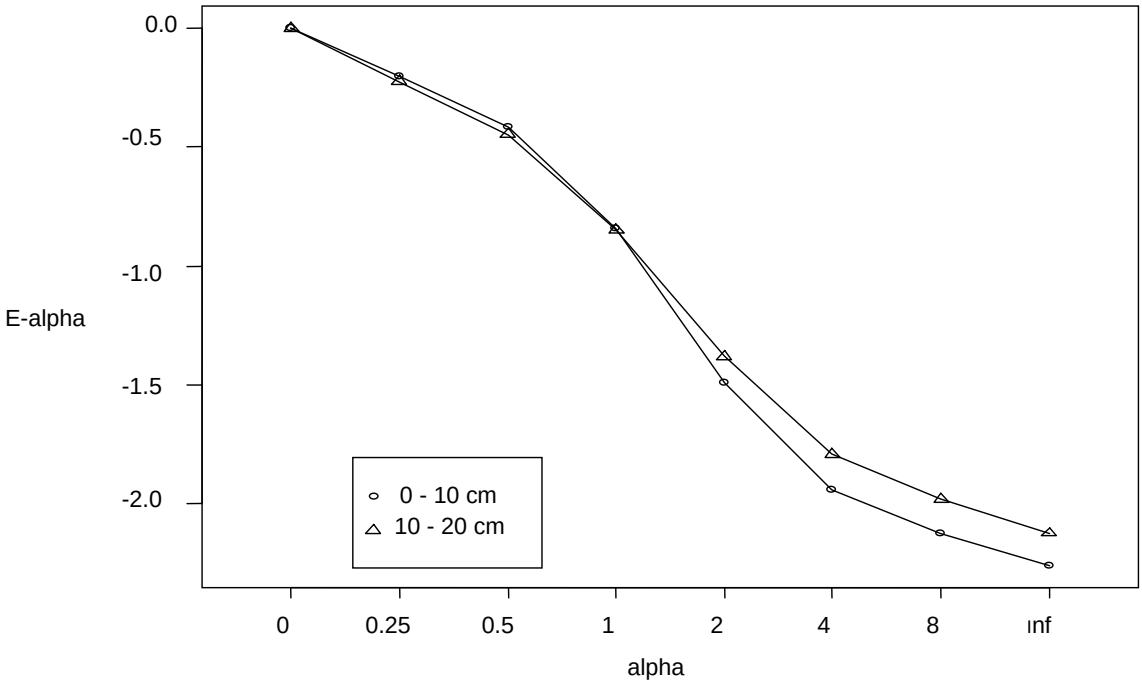

Figure 6. Evenness of *Fusarium* species under varying soil depths in Taita Taveta district, Kenya.

The abundance and richness of the fungus varied significantly with soil depth (P<0.05). The top soil had a higher *Fusarium* abundance (mean log (abundance+1) of 2.23) compared to the lower soil layer (mean log (abundance +1) of 1.65) (Table 3). The variability in abundance of *Fusarium* within each soil depth is presented in Fig. 7. The top layer of the soil was richer (mean richness of 2.87) than the lower soil layer (mean richness of 1.75) as shown in Table 3.

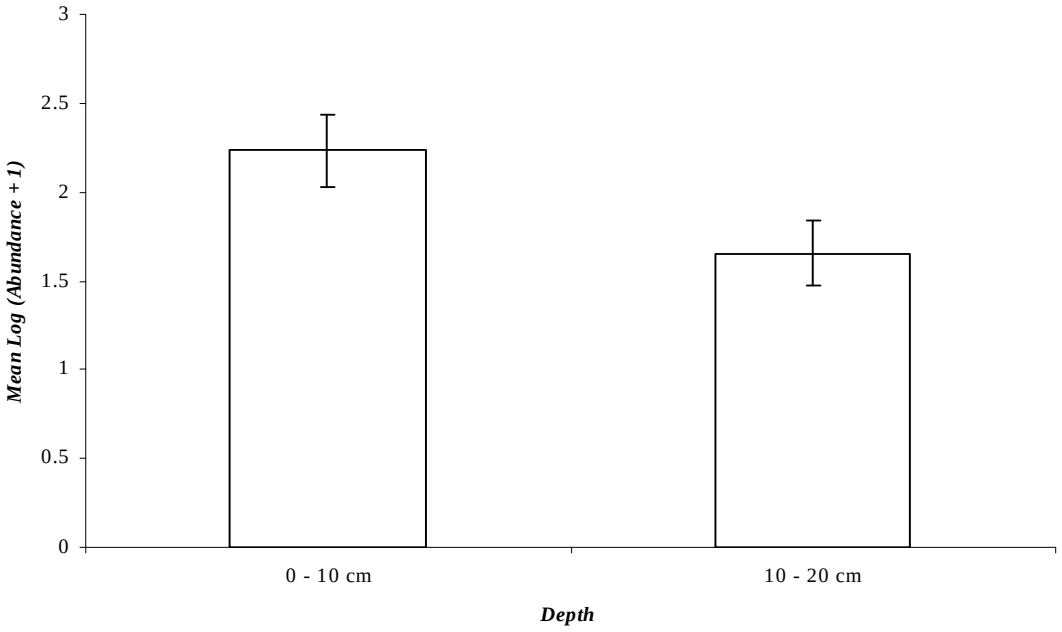

Figure 7. Abundance of *Fusarium* in the two soil depth levels in Taita Taveta district, Kenya.

Results further indicated that cultivated soil were higher in P, K, and Mg but low exchangeable acidity, N,C, and Fe, when compared with the forest soils (Table 4). A significant negative regression (P<0.05) between soil chemical parameters and fungal abundance, richness and diversity were abundance (r=-0.605), richness (r=-1.317) and diversity (r=-0.16) of soil Fusaria. Soil P and pH had a significant positive effect on abundance, richness and diversity of soil Fusaria. The results further indicated that other soil minerals, like C, Ca, Mn, Fe and Cu had no significant effect on the abundance, richness and diversity of soil *Fusarium* species (P>0.05) (Tables 5, 6 and 7).

There was also a significant negative correlation between soil N levels and *Fusarium* richness (r=-2.94) and diversity (r=-0.67) (P<0.05) and positive correlation between soil pH and P on abundance, richness and diversity of soil *Fusarium* (P<0.001).

Table 4. Mean values of soil chemical characteristics across the Land Use Types in Taita Taveta, Kenya.

Land use type	pH	Acidity	N (%)	C (%)	P (ppm)	K (m.e%)	Ca (m.e%)	Mg (m.e%)	Mn (m.e%)	Cu (ppm)	Fe (ppm)
Maize	4.65	0.37	0.24	1.76	37.8	0.37	2.64	2.91	0.63	1.36	40.7
Fallow	4.29	0.76	0.24	1.79	12.6	0.5	2.86	2.14	0.42	1.07	61.0
Nappier	4.39	0.75	0.21	1.71	19	0.41	2.73	2.09	0.52	1.78	33.0
Horticulture	4.97	0.22	0.2	1.78	44.9	0.61	2.68	2.75	0.59	0.82	52.3
Planted forests	3.51	2.03	0.42	2.30	5.8	0.17	2.35	1.16	0.74	1.07	89.3
Indigenous forests	3.88	1.12	0.51	2.85	19.9	0.29	2.69	0.81	0.64	1.14	76.9

Table 5. The correlation (r) coefficient between Fusaria abundance and the soil chemical parameters in soils from Taita Taveta, Kenya.

Element/ soil condition	Coefficient		p-value
Acidity	intercept	2.507	<0.001
	parameter	-0.605	<0.001*
C	Intercept	2.108	<0.001
	parameter	-0.080	0.593 ns
Ca	Intercept	1.703	<0.001
	parameter	0.09	0.402 ns
Cu	Intercept	2.020	<0.001
	parameter	-0.065	0.661 ns
Fe	Intercept	2.030	<0.001
	parameter	-0.00146	0.657 ns
K	Intercept	1.718	<0.001
	parameter	0.581	0.121 ns
Mg	Intercept	1.459	<0.001
	parameter	0.2501	0.009 ns
Mn	Intercept	1.967	<0.001
	parameter	-0.041	0.905 ns
N	Intercept	2.132	<0.001
	parameter	-0.593	0.407 ns
P	Intercept	1.597	<0.001
	parameter	0.01504	<0.001*
pH	Intercept	0.000	1.000
	parameter	0.456	0.019*

* Significant, ns= Not significant

Table 6. The relationship between Fusaria richness and the soil chemical parameters in soils from Taita Taveta, Kenya.

Element/ soil condition	Coefficient		p-value
Acidity	Intercept	3.520	<0.001
	parameter	-1.317	<0.001*
C	Intercept	3.103	<0.001
	parameter	-0.383	0.189 ns
Ca	Intercept	2.188	<0.001
	parameter	0.045	0.829 ns
Cu	Intercept	2.289	<0.001
	parameter	0.016	0.956 ns
Fe	Intercept	3.008	<0.001
	parameter	-0.01178	0.065 ns
K	Intercept	1.656	<0.001
	parameter	1.688	0.020*
Mg	Intercept	1.586	<0.001
	parameter	0.374	0.46 ns
Mn	Intercept	2.109	<0.001
	parameter	0.333	0.618 ns
N	Intercept	3.244	<0.001
	parameter	-2.94	0.033*
P	Intercept	1.535	<0.001
	parameter	0.03368	<0.001*
pH	Intercept	-2.79	0.082
	parameter	1.197	0.001*

* Significant, ns=Not significant

Table 7. The relationship between the diversity of Fusaria and the soil chemical parameters in Taita Taveta, Kenya.

Element/ soil condition	Coefficient		p-value
Acidity	Intercept	0.8201	<0.001
	parameter	-0.3160	<0.001*
C	Intercept	0.748	<0.001
	parameter	-0.1051	0.114 ns
Ca	Intercept	0.467	0.001
	parameter	0.0236	0.623 ns
Cu	Intercept	0.528	<0.001
	parameter	0.0011	0.987 ns
Fe	Intercept	0.661	<0.001
	parameter	-0.00222	0.129 ns
K	Intercept	0.3735	<0.001
	parameter	0.403	0.015*
Mg	Intercept	0.339	0.001
	parameter	0.0988	0.021*
Mn	Intercept	0.487	<0.001
	parameter	0.071	0.642 ns
N	Intercept	0.743	<0.001
	parameter	-0.670	0.034*
P	Intercept	0.3480	<0.001
	parameter	0.00790	<0.001*
pH	Intercept	-0.536	0.145
	parameter	0.2503	0.004*

* Significant, ns=Not significant

Soil K had a weak positive effect on soil *Fusarium* richness (r=1.688) and diversity (r=0.403) whereas Mg had a positive effect on abundance (r=0.25) and diversity (r=0.0988) of soil Fusaria (P<0.05).

Redundance analysis revealed that all the *Fusarium* species recovered in this study were positively correlated with soil P, pH, Mg, K, and Ca but negatively correlated with soil Mn, C, N, exchangeable acidity, Cu, and Fe (Figure 8). The following species were positively correlated; *F. graminearum, F. solani, F. avenaceum, F. xylarioides,* and *F. verticillioides* implying that their abundance was influenced by phosphorous. *F. poae* is also strongly correlated with the above species and its abundance is positively influenced by pH. *F. oxysporum* abundance was influenced by potassium while *F. torulosum, F. chlamydosporum, F. acuminatum,* and *F. sporotrichioides* were sensitive to calcium levels in the soil (Figure 8).

The low abundance, richness and diversity of Fusaria observed in the less disturbed ecosystems could be explained by the high levels of soil N and exchangeable acidity.

DISCUSSION

Distribution and diversity of soil *Fusarium* was influenced by land use type and soil management practices. Cultivated soils (maize and horticulture LUTs) which were highly disturbed recorded the highest pH, P, Mg and K as well as the highest diversity and abundance of the fungus. The populations of plant pathogenic species like *Fusarium oxysporum* and *F. solani* were found to be greater in cultivated soils due to presence of suitable hosts. The low occurrence of *Fusarium* species in indigenous forests soils could also be as a result of suppression by other predominant saprophytic fungi present or that the fungus is selected against through lack of suitable or susceptible host in these ecosystems. Disturbance caused by cultivation could also contribute to spread of the fungus through dispersal as the soils are turned over during tillage.

These findings were consistent with those of Wakelin *et al*., (2008) who demonstrated the effect of plant type and land management practices on abundance of soil *Fusarium.*the soils. Rheeder and Marasas, (1998) and Steinkellner and Langer (2005) also reported that land cover determined the occurrence of *Fusarium* species. Soil management system influenced the nutrients in the soil resulting into variation in soil chemical make up of the sampling plots that could have also contributed to variations in Fusarium distribution as explained above. Wakelin *et al*., (2008), Yergeau *et al*., (2006) and Jones *et al*., (1989) demonstrated that *Fusarium* population structure in the soil was correlated with soil P and Ca. Potassium positively impacted on richness and diversity of *Fusarium* species in the soil**.** Forests had the highest levels of C, N, and Fe hence low fungal occurrence. The low abundance, richness and diversity of Fusaria observed in the less disturbed ecosystems may have been as a result of high levels of soil N and exchangeable acidity. These findings are in agreement with those of Wang *et al*., (2004) who reported that increasing the levels of soil nitrogen reduced soil densities of *F. oxysporum.* Studies by Wu *et al.,* (2008) also demonstrated that addition of organic material with high C and N content reduced the abundance of *Fusarium oxysporum* in the soils, results that are consistent with the findings of this study. Rezacova *et al*., (2005) also observed that higher N fertilizer applications significantly suppressed the abundance of soil Fusaria.

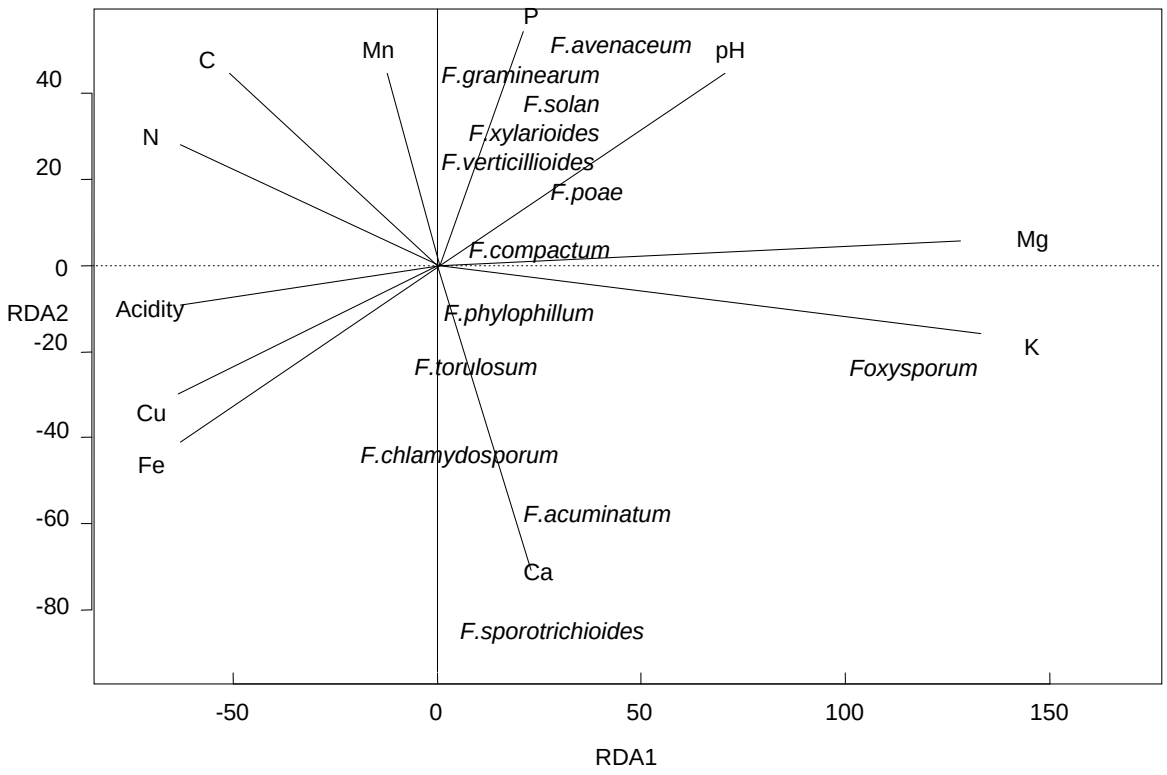

Fig. 8. Relationship between *Fusarium* species and soil parameters in Taita Taveta District, Kenya.

Fusarium isolates showed intolerance to high exchangeable acidity was inconsistent with the findings of Thompson *et al.*, (1993) who suggested that *Fusarium* species were tolerant to extremely low pH with the exception of *Fusarium graminearum.* Application of phosphorous may have resulted in high occurrence of *Fusarium* populations in these soils. *Fusarium oxysporum* and *F. solani* were dominant especially in cultivated soils suggesting that the soils had a tendency to build up large populations of the pathogenic which portends susceptibility of crops to *Fusarium* diseases.

Results from the Principal Component Analysis showed that Factor 1 and 2 explained up to 79.68 % of the influence of land use on the distribution of *Fusarium* sp. Factor 1 grouped the different isolates of Fusaria into two main sets with the most virulent species like *F. oxysporum, F. graminearum, F. poae* and *F. solani* on one side while the less virulent ones like *F. chlamydosporum, F. sporotrichioides, F. acuminatum, F semitectum* and *F. nelsonii* on the other side. *Fusarium graminearum, F. poae* and *F. solani* are known to be significant pathogens of maize and beans while *Fusarium chlamydosporum, F. sporotrichioides, F. acuminatum, F. semitectum* and *F. nelsonii* are mostly saprophytic and secondary colonists of necrotic or senescent tissues. Most of *Fusarium species* were recovered in this study were isolated from the disturbed LUTs (at 84.8 %).

According to Gomez *et al.*, (2007), management of the soil influences fungal propagules which could be attributed the level of competition among the predators. Disturbed ecosystems, with diverse plant cover, would provide capacity to support a higher diversity of competing species. Planted forests had the lowest diversity (H=0.09) as only species capable of colonizing the plants were present. There appears to be a relationship between diversity of *Fusarium* species and the type of vegetation present. A greater diversity of vegetation was presumed to support a greater diversity of *Fusarium* species, and the results from soils under nappier and planted forests had the least population of *Fusarium.* High abundance of the fungus in the top soil may be due to rhizosphere effect.

CONCLUSION

The study showed that plant cover and soil management system such as addition of fertilizers and tillage determine the distribution and abundance of soil

Fusarium species. *Fusarium* species were widely distributed and could potentially be used as biological indicator to assess the effects of anthropogenic disturbance in agricultural ecosystems.

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