British Microbiology Research Journal
9(4): 1-15, 2015, Article no.BMRJ.18034
ISSN: 2231-0886

SCIENCEDOMAIN *international*
www.sciencedomain.org

Distribution and Diversity of Indigenous *Trichoderma* species in Machakos County, Kenya

P. K. Maina[1*], P. M. Wachira[1], S. A. Okoth[1] and J. W. Kimenju[2]

[1]School of Biological Sciences, University of Nairobi, P.O.BOX 30197-00100, Nairobi, Kenya.
[2]Department of Plant Science and Crop Protection, University of Nairobi, P.O.Box 30197-00100, Nairobi, Kenya.

Authors' contributions

This work was carried out in collaboration between all authors. Author PKM carried out the experiments, performed the statistical analysis, and wrote the first draft of the manuscript and managed literature searches. Authors PMW, SAO and JWK designed the study, managed the analyses of the study and literature searches and proofread the final draft. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734//BMRJ/2015/18034
Editor(s):
(1) Laleh Naraghi, Plant Disease Research Department, Iranian Research Institute of Plant Protection, Tehran, Iran.
Reviewers:
(1) Igor Villela Marroni, Department of Basic Health Sciences, Rua Sarmento Leite, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil.
(2) Klára Kosová, Division of Crop Genetics and Breeding, Crop Research Institute, Prague, Czech Republic.
Complete Peer review History: http://sciencedomain.org/review-history/9947

Original Research Article

Received 31st March 2015
Accepted 20th April 2015
Published 29th June 2015

ABSTRACT

Aim: This study was undertaken in order to determine the effect of land-use intensification on occurrence, distribution, and diversity of *Trichoderma* fungus.
Study Design: Cross-sectional study.
Place and Distribution of Study: Mycology Laboratory, University of Nairobi between March and September, 2014.
Methodology: Soil samples were collected from both Mwala and Kauti irrigation blocks in Kabaa irrigation scheme of Machakos County, in Kenya under three land use types (LUTs): intensively cultivated farmlands under irrigation, rainfed intensively cultivated farmlands and undisturbed lands. A total of 100 soil samples were obtained from the top 0- 20 cm depth. *Trichoderma* species were isolated using the dilution plate technique using *Trichoderma*-selective media (TSM).
Results: A total of 369 *Trichoderma* isolates were recovered from the three LUTs. These were identified and classified into eleven species. The species identified were: *T. harzianum, T. koningii,*

**Corresponding author: E-mail: wmaina89@yahoo.com;*

T. viride, T. asperellum, T. atroviride, T. spirale, T. virens, T. tomentosum, T. brevicompactum, T. crassum and T. hamatum. The most abundant *Trichoderma* species was *T. harzianum* with a frequency of isolation of 38.87%, followed by *T. koningii* and *T. viride* at 18.03 and 15.49%, respectively. *Trichoderma hamatum* had the least isolation frequency at 0.41%. *T. harzianum* also had the widest distribution. The difference in abundance of *Trichoderma* in the three LUTs was significant (*P*=0.05). The undisturbed lands had a higher abundance of *Trichoderma* compared to the disturbed areas. Mwala irrigation block A had the least abundance while block D which is more recent in cultivation had highest mean abundance of *Trichoderma*. Difference in *Trichoderma* species mean richness between LUTs was not significant (*P*=0.203). Undisturbed lands had the highest richness. Undisturbed lands also had the highest diversity while irrigated lands were the least diverse

Conclusion: Enhanced land-use intensification lowers the abundance and diversity of *Trichoderma* in the soil.

Keywords: Trichoderma; biodiversity; biocontrol; fungi; pathogen; land-use.

1. INTRODUCTION

A rapid increase in human population in Kenya, coupled with shortage of arable land has posed a great challenge on food security [1]. The situation is made even worse by unpredictable weather patterns, declining soil fertility, upsurge in prevalence of crop pest and pathogens [2,3]. Since the arable land remains inelastic, there is enhanced intensification in agricultural production in order to mitigate the food insecurity situation. Agricultural intensification has many negative implications. Farmers result in increased use of chemical inputs that not only increases the cost of production but also leads to environmental contamination.

Soil is a dynamic, living, natural body that is vital to the function of terrestrial ecosystems [4]. The current increased intensification affects the soil as it leads to loss of soil biodiversity and this affects the status of soil health which is critical to sustainable agriculture [5]. According to Nannipieri et al. [6], higher soil biodiversity is an indication of the status of its health. Therefore, soil microbial populations may be used as indicators of soil health since an ecological balance between soil borne pathogens and organisms with biocontrol potential naturally suppresses the incidence of diseases [7]. One of the cost effective and eco-friendly way for higher agricultural productivity is maintenance of a higher soil biodiversity. *Trichoderma,* a soil fungus, is one of the components of soil biodiversity that has capacity of maintaining soil health. Members of this genus like *T. harzianum, T. atroviride, T. atroviridis, T. asperellum* and *T. virens* are antagonists against important soil borne crop pathogens. This fungus is cosmopolitan, colonising a wide range of soil niches from cool temperate to tropical climates [8].

Members are commonly present in the soil's top horizons [9]. Other *Trichoderma* species have been recovered in extreme environments like mangrove swamps, salt marshes and estuarine. Okoth et al. [10] carried out a study in Kenya in two bench mark sites with significant land use intensification and being biodiversity hot spots. They reported that the most frequently isolated species was *T. harzianum* while other species had a restricted distribution due to difference in ecological parameters and type of crop grown. Previous studies have revealed that *Trichoderma* species can be influenced by soil temperature [11,12,13] soil moisture [14], soil pH range [15], salinity [13,16], among other soil factors.

Trichoderma species have been gaining importance as a potential and effective biocontrol agent and also as a plant health promoter due to their fascinating mechanisms like the production of antifungal metabolites, competition for space and nutrients, mycoparasitism, induction of defense responses and promotion of salinity and drought tolerance [17,18]. Several reports indicate that *Trichoderma* species can effectively suppress crop pathogens [19]. Several studies in Kenya have demonstrated ability of *Trichoderma* isolates to manage some crop diseases [20,21,22]. Harman et al. [23] have shown that the genus *Trichoderma* can induce localised or systematic resistance to diseases through the release of metabolites that tends to promote plant production of ethylene or terpenoid phytoalexins.

Studies have confirmed that agricultural intensification has effects on soil *Trichoderma* biodiversity [24,25,26]. As intensification

becomes a real phenomenon in order to feed the growing population, its impact on soil biodiversity need to be assessed. According to Okoth et al., [10], land-use types have an effect on abundance, richness and diversity of *Trichoderma*. Information on the occurrence and diversity of indigenous *Trichoderma* species in Kenya under intensively cultivated lands is scanty. There is need to assess the effect of land-use intensification on the occurrence and diversity of this soil fungus. Quantification of *Trichoderma* in the soil would assist in estimating the capacity of soil in controlling soil-borne fungal pathogens. This study therefore aims at evaluating the effect of land-use intensification on *Trichoderma* occurrence and diversity. This will be achieved by comparing *Trichoderma* biodiversity in intensively cultivated lands with those from undisturbed lands.

2. MATERIALS AND METHODS

2.1 The Study Area and Soil Sample Collection

Soils were obtained from Kabaa irrigation scheme, in Mwala Sub-county of Machakos County, Kenya. This county experiences arid and semi-arid type of climate. The temperatures vary from 6 to 29ºC. The study area was selected due to variation of land use which included high intensively cultivated land and also availability of rainfed land use and adjacent undisturbed land. The main crops grown under irrigation include French bean, maize, tomatoes, common bean and kales. Under rain-fed agriculture, diverse crops are grown including maize, common beans, sorghum, cassava, kales, millet among other crops. The undisturbed lands had grass as the main vegetation type. The study was replicated in two regions within the county; which were Mwala and Kauti irrigation schemes. Mwala irrigation scheme is located in Lower Midland zone 4, majorly occupied with cambisol soils. Mwala irrigation scheme is divided in to four blocks; A to D based on their history of cultivation; with block A having a longest period of cultivation as it was opened in 2006, followed by block B opened in 2009, block C opened in 2010 and block D opened in 2011. Kauti irrigation scheme lies in the Upper midland zone 4 and is characterized with Alfisol and acrisol soils. The scheme is divided into two main blocks based on elevation, the upper and the lower blocks.

In each of the two regions, soils were sampled from the three land use types (LUTs): intensive agricultural lands under irrigation, rainfed intensive agricultural lands and undisturbed lands. From each sampling point, 12 soil sub-samples were obtained as described by Okoth et al. [10]. Two circles measuring 3 m and 6 m radii were drawn and 4 and 8 soil samples were augured at 0-20 cm depths, respectively (Fig. 1).

The soil samples were mixed thoroughly into a single composite sample and a 100 g sub-sample taken for *Trichoderma* isolation. The soil auger was sterilised for each sampling point to avoid cross contamination. A total of 100 samples were collected from the two regions, in the three LUTs. These samples were transported to in paper bags to mycology laboratory in University of Nairobi (Chiromo campus) where they were kept at 5ºC awaiting further analysis.

2.2 *Trichoderma* Isolation and Identification

Soil dilution plate technique was used to isolate *Trichoderma* strains from the soil using *Trichoderma* Selective Medium (TSM) [27]. Plating was done from the second and third dilution in three replicates for each dilution. The plates were then incubated in the dark at 20ºC for 10 d to allow fungal growth [11]. *Trichoderma* colonies were then sub-cultured onto a half strength Potato Dextrose Agar (PDA) plates amended with chloramphenicol (½ PDA+c). Single spore cultures were plated on ½ PDA+c and incubated at 20ºC for 14 day at 15, 25, 30 and 35ºC. For the first 7 days, the *Trichoderma* colonies were incubated in the dark then under 24 h blue light to encourage sporulation [27]. The isolates were identified to species level following the taxonomic keys of Samuels *et al.,* [28] and Gams and Bissett, [29]. Colony characters, growth rates in culture and morphological characters were used in identification. Microscopic examination was carried out by mounting the culture in lactophenol cotton blue but for size measurements, KOH and water was used as the mounting fluid.

2.3 Statistical Analysis

The data obtained was subjected to analysis of variance (ANOVA) using statistical software GenStatver. 9.0 (VSN International Ltd). *Trichoderma* mean abundance, mean richness and Shannon index will be calculated as described by Tuomisto [30]. Significance was evaluated at $P < 0.05$ for all analyses and means separation accomplished by Fisher's protected least significant difference (LSD) test.

3. RESULTS AND DISCUSSION

3.1 Isolation of *Trichoderma* Species across the Various Land Uses

From the 100 soil sampling points across the different land use types, a total of 369 *Trichoderma isolates* were recovered. The isolates were grouped into 11 *Trichoderma* species. The species include; *T. harzianum, T. koningii, T. viride, T. asperellum, T. atroviride, T. spirale, T. virens, T. tomentosum, T. brevicompactum, T. crassum* and *T. hamatum.* The most abundant *Trichoderma* species was *T. harzianum* with a frequency of isolation of 38.87% (Table 1). This species was followed by *T. koningii* and *T. viride* at 18.03 and 15.49%, respectively. *Trichoderma hamatum* had the least isolation frequency at 0.41% and was only isolated form Mwala rainfed farmlands (Table 1). Among the *Trichoderma* species, *T. harzianum* had the widest distribution with representatives from all the LUTs under study. Some species were isolated from only one land use type; *T. virens* (Kauti undisturbed), *T. brevicompactum* (Kauti irrigated), *T. crassum* (Mwala undisturbed) and *T. hamatum* (Mwala rainfed).

Trichoderma asperellum, T. virens and *T. crassum* were only recovered from undisturbed farmlands while *T. tomentosum* was isolated from rainfed farmlands only. *Trichoderma tomentosum* was isolated from rainfed lands only while *T. brevicompactum* was only isolated from irrigated areas of Kauti. Isolates of *T. crassum* and *T. hamatum* were restricted to Mwala region, being isolated from undisturbed and rainfed lands, respectively.

The occurrence of *Trichoderma* varied negatively with age of cultivation. The lands with longer history of cultivation had lower abundance of this fungus. This was reflected in Mwala irrigation blocks, where block D which has a shorter history of cultivation having the highest isolation frequency at 54.17% while block A having the least isolation frequency at 4.16% (Fig. 2). From this block, only *T. harzianum* could be isolated while from block D, three species were isolated, namely *T. harzianum, T. viride* and *T. spirale* (Table 2). The isolation of individual species also varied with age of cultivation. Although *T. harzianum* was the most isolated species within these blocks at 58.34%, it was more abundant in block D (Table 2). *Trichoderma viride* and *T. spirale* which were the second and third most abundant species, at 33.33 and 8.33%, respectively, were only isolated from block D (Table 2) which had the shortest history of cultivation.

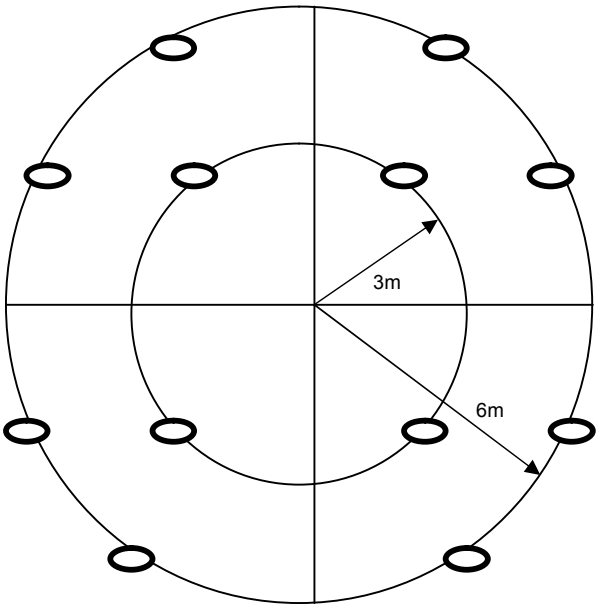

Fig. 1. Schematic representation of the twelve soil sampling points which comprised one main sampling point of the 100 sampling points

Table 1. Frequency of isolation of *Trichoderma* species from the three land-use types in the two regions

***Trichoderma* spp**	**Proportion (%) per land use type**						
	Mwala irrigated	**Mwala rainfed**	**Mwala undisturbed**	**Kauti irrigated**	**Kauti rainfed**	**Kauti undisturbed**	**overall%**
T. harzianum	58.34	28.57	40.78	33.33	60.61	37	**38.87**
T. koningii	0	0	24.8	39.4	0	15.25	18.03
T. viride	33.33	0	18.65	0	0	15.01	15.49
T. asperellum	0	0	5.53	0	0	11.35	8.43
T. atroviride	0	34.29	1.64	0	21.21	9.93	7.61
T. spirale	8.33	0	6.97	0	0	5.08	5.41
T. virens	0	0	0	0	0	6.38	3.7
T. tomentosum	0	7	0	0	18.18	0	0.89
T. brevicompactum	0	0	0	27.27	0	0	0.61
T. crassum	0	0	1.64	0	0	0	0.55
T. hamatum	0	17.14	0	0	0	0	0.41
Frequency of isolation (%)	1.65	2.4	33.45	2.26	2.26	57.98	100%

Table 2. Frequency of isolation of *Trichoderma* species in Mwala irrigation blocks A to D

***Trichoderma* spp**	**% of isolation in the irrigation blocks**				
	A	**B**	**C**	**D**	**Overall %**
T. harzianum	100	33.33	50	69.24	58.34
T. koningii	0	0	0	0	0
T. viride	0	66.37	50	15.38	33.33
T. asperellum	0	0	0	0	0
T. atroviride	0	0	0	0	0
T. spirale	0	0	0	15.38	8.33
T. virens	0	0	0	0	0
T .tomentosum	0	0	0	0	0
T. brevicompactum	0	0	0	0	0
T. crassum	0	0	0	0	0
T. hamatum	0	0	0	0	0

The results revealed that the abundance of *Trichoderma* species was affected by the land use type. The abundance of this fungus for different LUT was significantly different (P<0.01). The undisturbed lands had a higher abundance of *Trichoderma* species than the intensively cultivated lands (Fig. 3). These results were true for the two regions under study (Figs. 4 and 5). However, in both regions, the rainfed farmlands had a higher mean abundance than the irrigated lands.

The difference in *Trichoderma* species abundance between irrigation blocks in Mwala was not significant (P=0.418). However, block D had highest mean abundance of *Trichoderma* followed by block B (Fig. 3). Block D has a recent history of cultivation compared to the others as it was opened in 2011. Block A, which has the longest history of cultivation since 2006, had the least mean abundance of *Trichoderma* species (Fig. 6). Difference in *Trichoderma* species richness between LUTs was not significant (P=0.203). However, undisturbed lands had the highest mean richness. The irrigated farmlands had the least mean richness of *Trichoderma* (Fig. 7). This trend was replicated in the two regions under study.

The difference in *Trichoderma* species richness among Mwala blocks was not significant (P=0.285). However block D had the highest mean richness while A had the least (Fig. 8). This study further revealed that undisturbed lands had the highest *Trichoderma* species diversity (Fig. 9). The irrigated farmlands had the least mean Shannon index. However within Kauti region, rainfed lands were the least diverse. Within Mwala irrigation blocks, block D had the highest diversity, followed by C. Block A was the least diverse (Fig. 9).

Among the Mwala irrigation blocks, block D had the highest mean diversity followed by block C while block A had the least diversity (Fig. 10).

This study has revealed that *Trichoderma* is widely distributed in the study area. In a previous study on occurrence of *Trichoderma* from different land-use types by Okoth et al. [10], 9 and 10 species were isolated from Embu and Taita regions of Kenya, respectively. It has also been reported that members of this genus are cosmopolitan and occur in diverse ecosystems and climatic regions [31]. The frequent occurrence of *Trichoderma* species in the soils under different crop species is in accordance with the fact that species of *Trichoderma* are an abundant and biologically important component of soil micro-flora, though differences in their abundance can occur [28]. The occurrence of *Trichoderma* species is modulated by several factors which include microclimates, substrate availability, as well as complex ecological interactions [32]. Survival ability of *Trichoderma* in diverse geographical areas can be attributed to their high reproductive capacity, competitive capability and diverse metabolism [33].

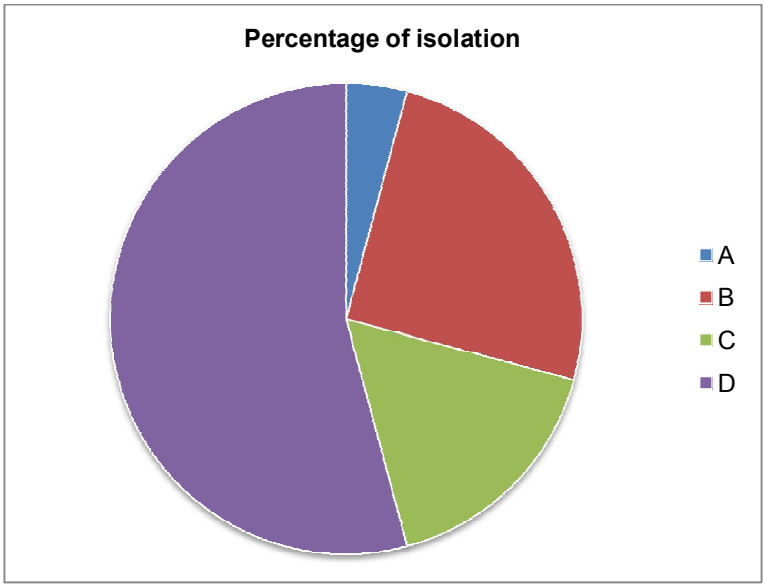

Fig. 2. Frequency of isolation of *Trichoderma* species in Mwala irrigation blocks A to D

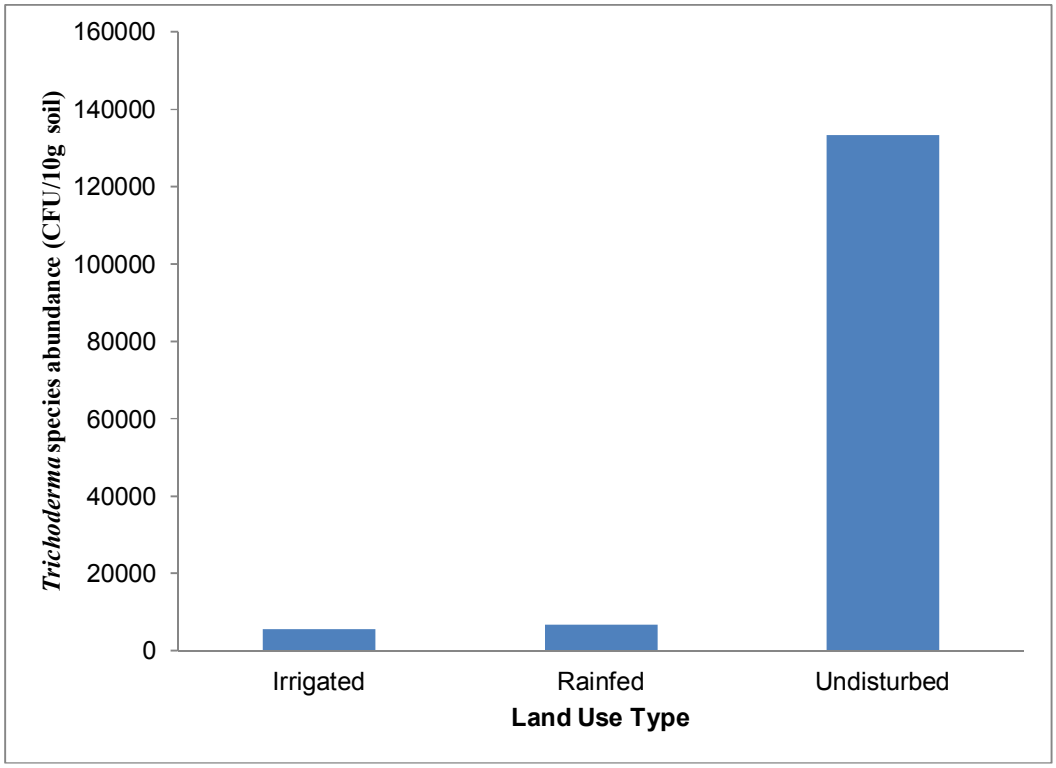

Fig. 3. *Trichoderma* species mean abundance for the three land-use types

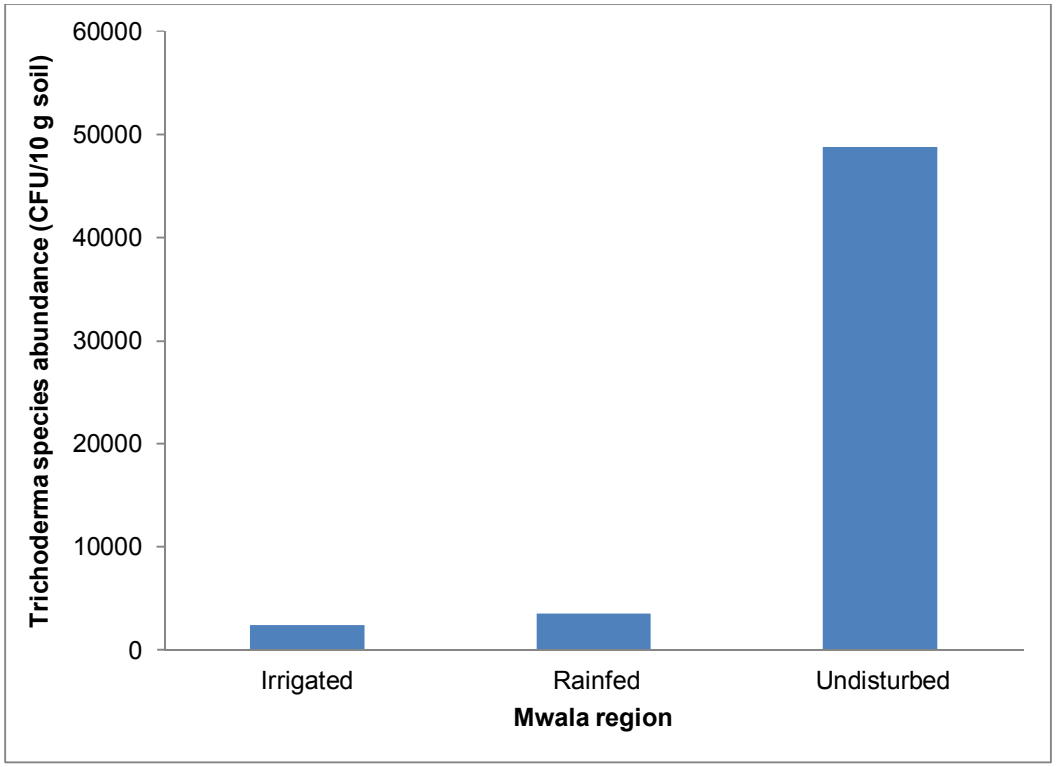

Fig. 4. *Trichoderma* species mean abundance in three land-use types within Mwala region

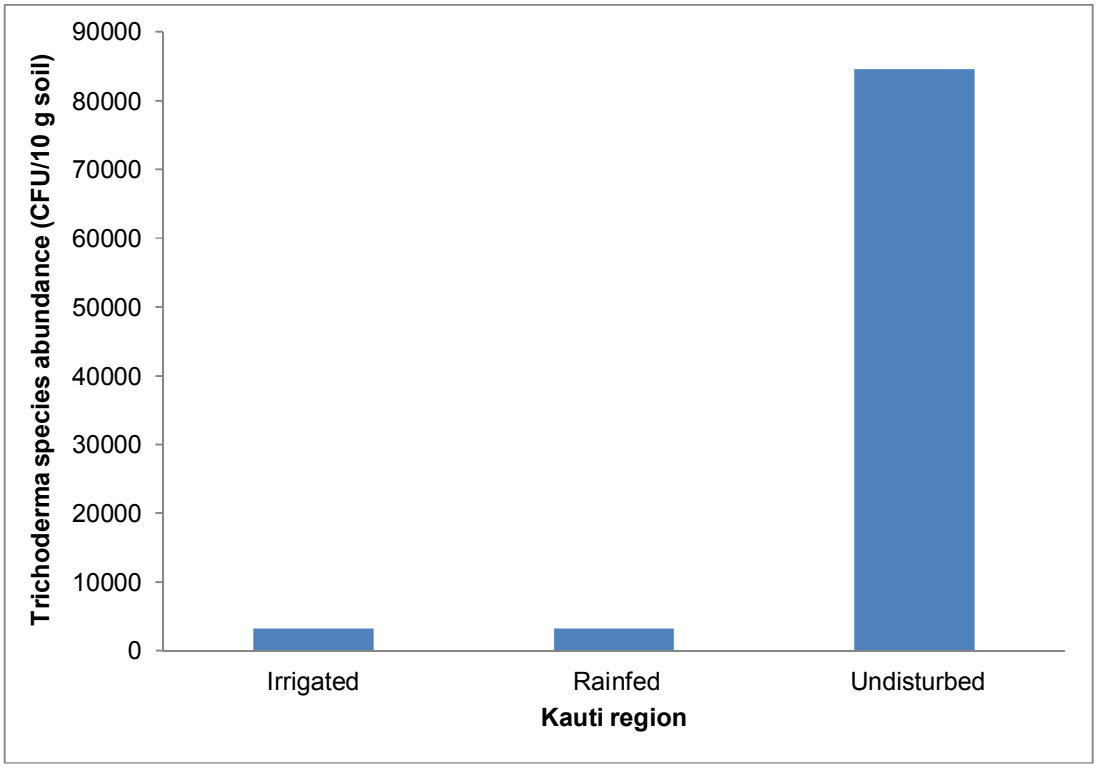

Fig. 5. *Trichoderma* species mean abundance in the three land-use types within Kauti region

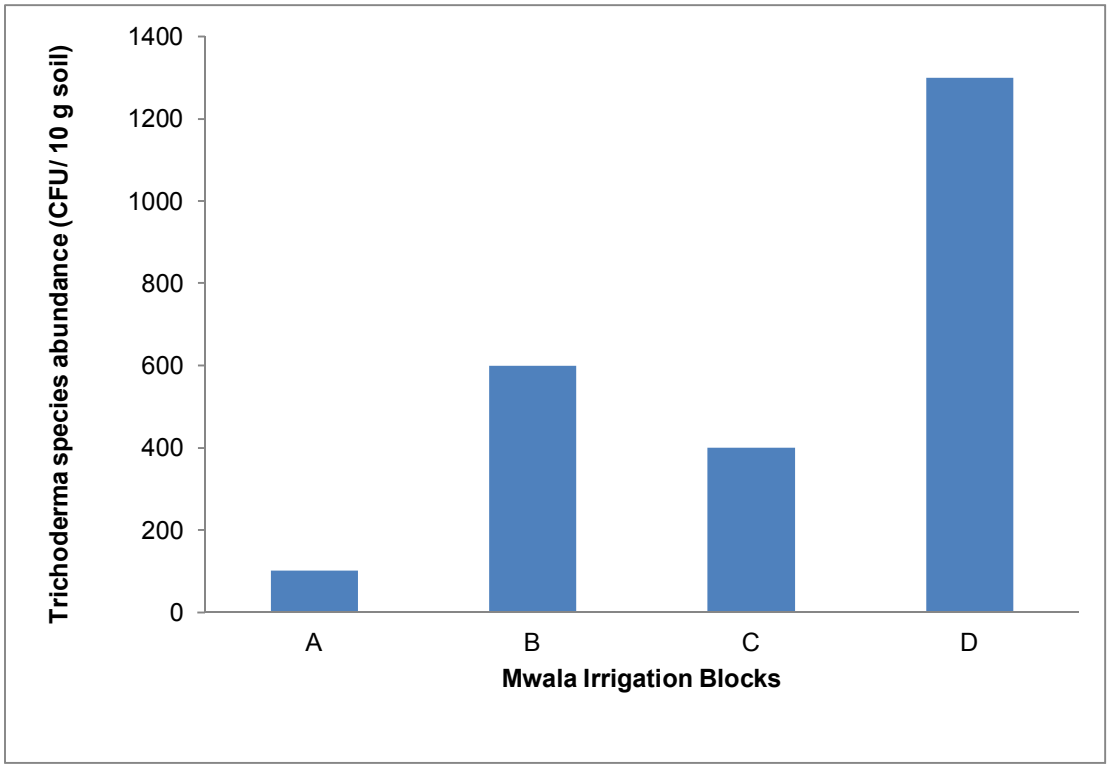

Fig. 6. *Trichoderma* species mean abundance in the four irrigation blocks in Mwala region

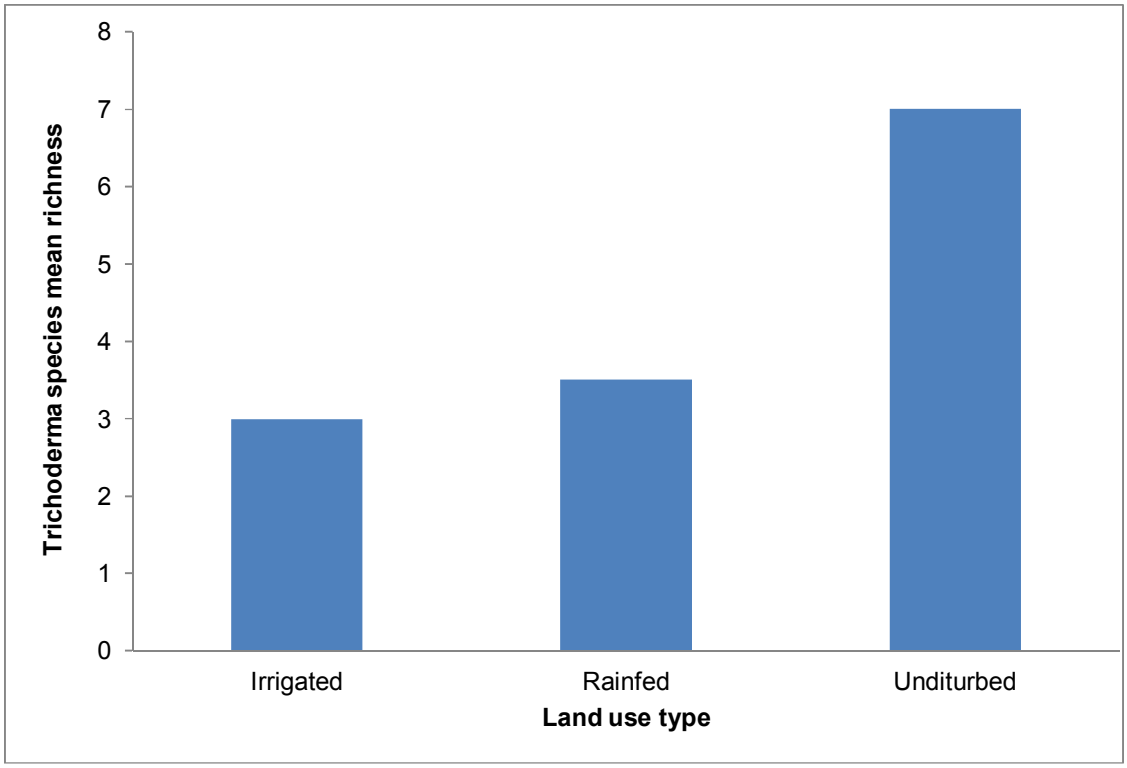

Fig. 7. *Trichoderma* species richness for the three land use types.

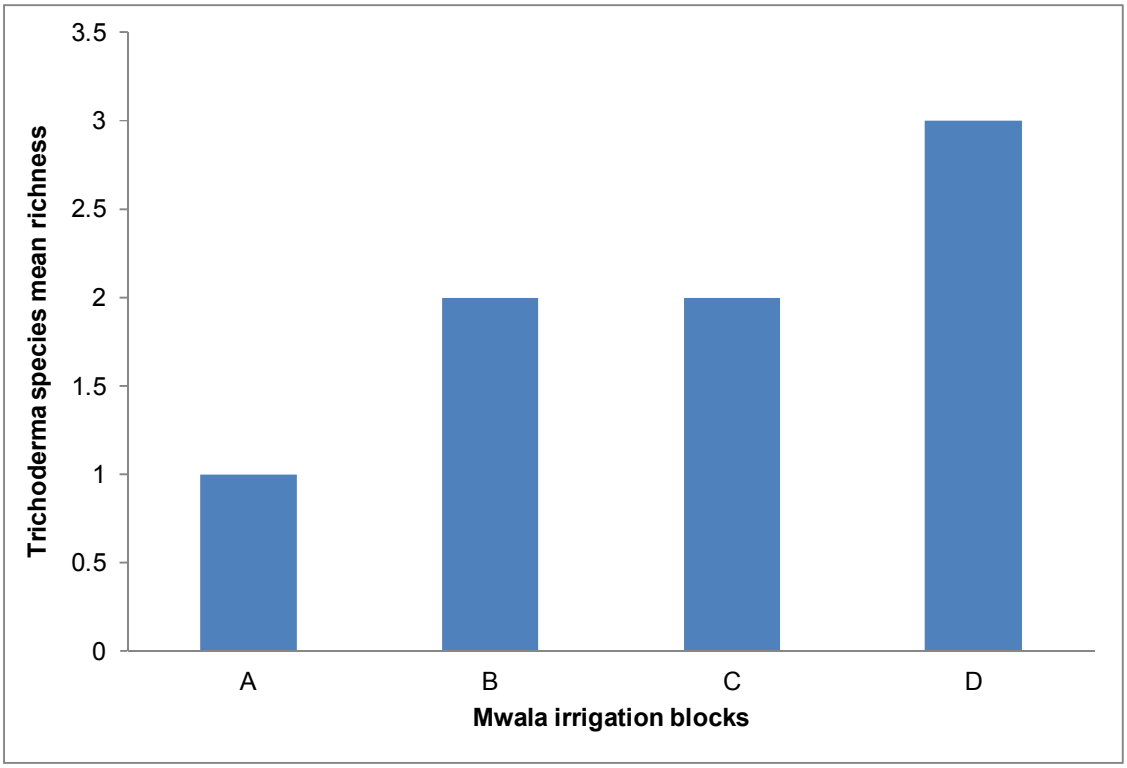

Fig. 8. *Trichoderma* species richness within Mwala irrigation blocks

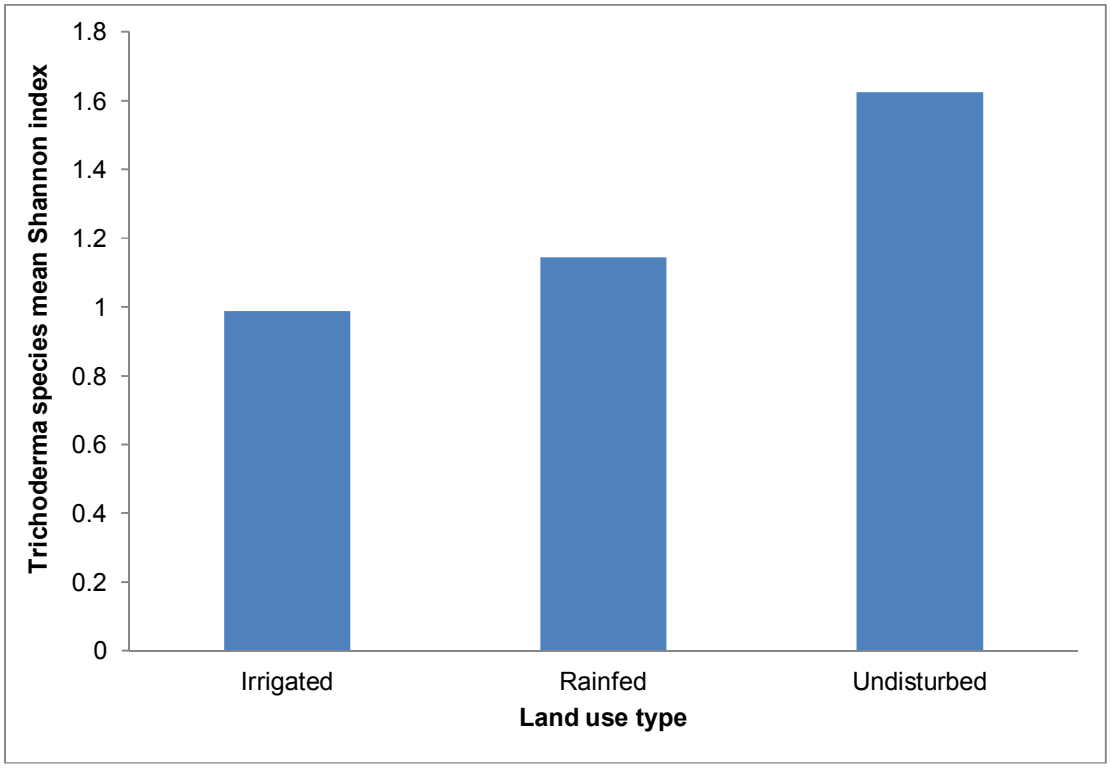

Fig. 9. The diversity of *Trichoderma* species in the three land-use types

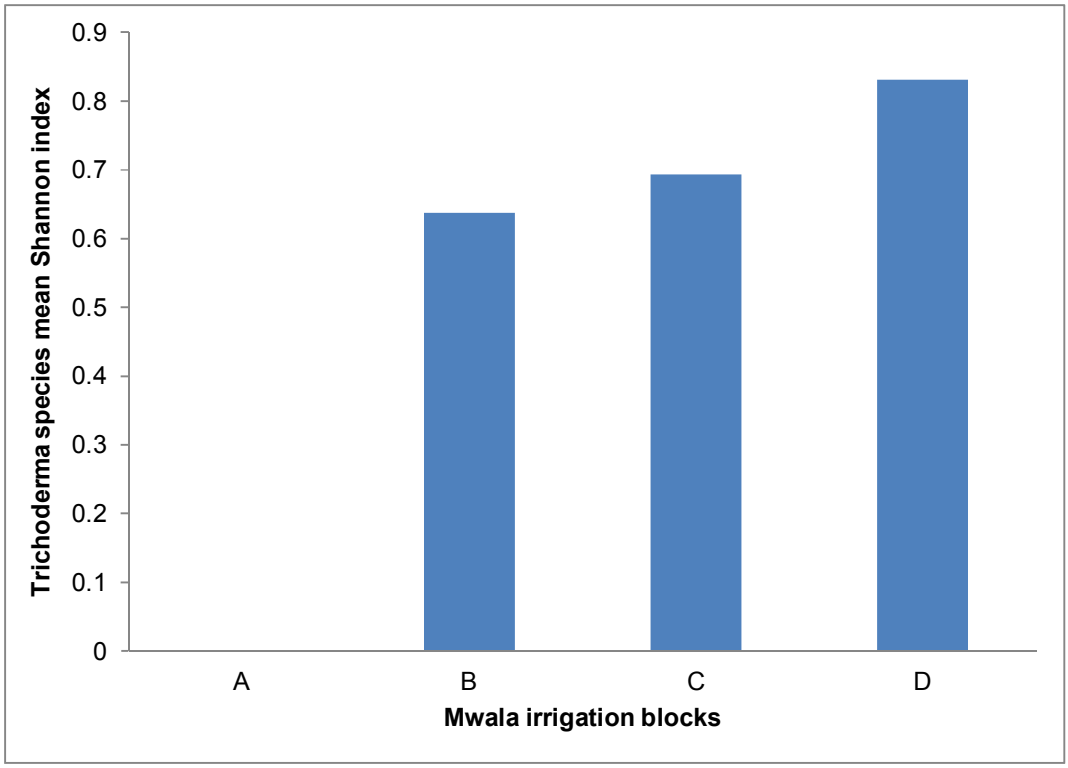

Fig. 10. *Trichoderma* species mean Shannon indices for the four Mwala irrigation blocks

Results of this study revealed that *T. harzianum* was the mostly frequently isolated species with a frequency of 38.87% (Table 1). This showed that it was the most dominant in the region and was therefore isolated from all the land use types. *Trichoderma harzianum* species is known to be strongly rhizosphere competent and proliferates best in soils rich in organic matter and plant root exudates. This may explain why this fungus is abundant in soils in this study. In agreement to this study, Okoth et al. [10], reported that *T. harzianum* was the most abundant species in two ecologically different regions in Kenya. In a similar study covering Russia, Siberia and the Himalayas, Kullnig, et al. [34] isolated *T. harzianum, T. asperellum, T. atroviride, T. ghanense, T. hamatum, T. koningii, T. oblongispirum,* and *T. virens,* with *T. harzianum,* being the most prevalent species. Sun et al. [26] also reported that *T. harzianum* was the most prevalent species in China soils. A study by Jaklitsch [35] covering 14 European countries in temperate climate detected 75 species with *T. harzianum* being the most abundant.

However, these results do not agree with those reported by Devi et al. [36] who isolated *Trichoderma* strains from various points in India subcontinent. Out of the 70 isolates they obtained, the most abundant species was *T. Longibrachiatum*. However, *T. harzianum, T. asperellum* and *T. virens* were also isolated similar to this study. Similarly, Attitalla et al. [37] isolated *T. harzianum* from only five of the 23 soil samples examined from Al-Jabal AL-Akhdar region of Libya. This could be attributed to geographical and climatic differences. Sun et al. [26] reported the effect of temperature on *Trichoderma* distribution with some species only occurring in cool regions. For example, *T. polysporum* and *T. viridescens* were restricted to cooler regions while *T. brevicompactum, T. erinaceum* and *T. ghanense* were prevalent in hot areas. Similarly, in this study, *T. virens, T. brevicompactum T. crassum* and *T. hamatum* had a more restricted distribution and were only isolated from only one land-use type. This could be attributed, probably to their low rhizosphere competence or other unfavourable soil factors. Okoth et al. [10] reported that although *T. harzianum* had the widest distribution, *T. reesei, T. asperellum,* and *T. polysporum* were only isolated from Taita, a region of relatively elevated temperatures. *Trichoderma citrinoviride* and *T. aggressivum* were only isolated from Embu, a region of lower temperature.

This study revealed that disturbance has significant impact on abundance of *Trichoderma* species. The undisturbed lands had the highest abundance, richness and diversity of *Trichoderma*. These results were evident in the regions of Mwala and Kauti. This could be attributed to the fact that less disturbed soils are naturally balanced to support a higher *Trichoderma* diversity. Undisturbed lands are characterised by a high floristic diversity, which could have influenced the greater *Trichoderma* diversity. In this study, it seems that some agricultural practices carried out by farmers could have had a negative impact on *Trichoderma* in the soil. Most farmers in the study area grow annual crops. This could have contributed to reduced organic matter in the soil as they harvest and take away the crop plants from the fields. These results are similar to those of Okoth et al. [10] who reported a higher occurrence of *Trichoderma* in the less disturbed soils. In contrast, however, Sun et al. [26] reported a higher diversity in vegetable soils in China than the pasture soils probably due to cropping system adopted that would favour a higher abundance and diversity of *Trichoderma.*

Bourguignon, [38] demonstrated that different crops and cropping regimes affect *Trichoderma* populations. Some crops grown by farmers could also be producing root exudates with antifungal activity and hence contributing to low *Trichoderma* populations in agricultural farmlands. Celar, [39] demonstrated that onions could cause decrease in *T. harzianum, T. viride* and *T. longibrachiatum*. Irrigaon may also reduce *Trichoderma* populations in the soils. According to Eastern and Butler, [40] extreme soil water content have a detrimental effect on the hyphal growth, spore production and germination of *Trichoderma*. The effect of use of inorganic fertilizers could have contributed probably to rise in pH and hence negatively affecting *Trichoderma* populations. Similarly, tillage is known to affect the soil physical and chemical environment in which the soil organisms live, thereby affecting soil *Trichoderma* in different ways. Janusauskaite et al. [41] have demonstrated that tillage intensity results in lower organic carbon and nitrogen and lowers soil quality, factors that would lower *Trichoderma* occurrence and diversity. According to Torensan et al. [42], soil management practices like tillage, fertilizer application, addition of organic manure, application of pesticides and irrigation may greatly negatively affect soil microbial populations. Muniappan and Muthukumar [43]

also reported that soil pH negatively influenced relative abundance of *T. koningii* while soil phosphorous affected it positively.

In spite of their coexistence in many soils, populations of some of the *Trichoderma* species were negatively related to each other. This suggests that these soil fungi compete in the soil environment or the fungi may be reacting variedly to the given environmental conditions. The first view is supported by the fact that strains of *T. viride* are known to be highly competitive and are known to proliferate best in the presence of healthy plant roots, whereas, *T. koningii* tends to occur in diverse soil conditions [28,44]. The second view is supported by the fact that soil pH has been thought to be of great importance to the activity and occurrence of *Trichoderma* species [23,45,46]. Kredics et al. [45] showed that species of *Trichoderma* grow optimally around pH 4.0 to 5.0, and exhibit little or no growth below pH 2.0 or above pH 6.0. This clearly shows that even the taxa within a genus can respond differently to the same environmental factors. Eastburn and Butler [47] also reported that soil pH had significant influence on the distribution of *T. harzianum* in a wide pH range of 6.2 to 7.9. Simon et al. [48] reported that application of ammonia to the soil can increase the populations of *Trichoderma* species.

The intensity of land use was found to have an effect on *Trichoderma* occurrence, richness and diversity. Wu et al. [49] reported that agricultural practices alter mycofloral diversity. Further, according to Lehman et al. [4], human disturbances, land management, cultivation, climatic factors, elevation, agriculture and environmental variability modify the diversity and ecology of microfungi. Though there may be important abiotic or biotic factors, which were not accounted for in this study, the establishment and wide-spread occurrence of *Trichoderma* species, appears to be more directly determined by the environment and anthropogenic activities. A similar conclusion was reached by Geisseler and Scow, [50], Attitalla et al. [37]; Okoth et al. [10]; and Sariah et al. [51]. They found that the environment had the greatest effect on the densities of several species of *Trichoderma*. Other factors of primary importance are those involving competition, antagonism and synergism among soil microorganisms.

The results further revealed that the history of cultivation had an effect on *Trichoderma* abundance, richness and diversity. Within Mwala irrigation blocks, block A have been in cultivation since 2006 had lower abundance, richness and diversity while a more recent block D (opened in 2011) had the highest abundance, richness and diversity of *Trichoderm*a (Fig. 2). Long history of cultivation may have led to changes in soil organic matter levels and addition of synthetic chemicals. Studies have shown that changes in *Trichoderma* populations tend to occur in response to temporary changes in soil moisture, soil organic matter, soil temperature and nutrient availability [30,46]. Tillage represents a disturbance of the soil habitat and can mechanically disrupt filamentous organisms such as *Trichoderma*, decrease soil structure, and alter water and nutrient content and distribution [52]. Plant species also exerts a selective pressure on soil fungal communities [43,53,54]. This could account for the difference in abundance, richness and diversity of *Trichoderma* between the farmlands with different histories of cultivation. The results indicate that, as period of cultivation increases, there is likelihood of losing important soil fungi such as *Trichoderma*. This has subsequent negative consequences as loss of inherent capacity of soil to maintain soil health is lost. According to Lehman et al. [4], activities associated with intensive agriculture such as aggressive soil tillage, annual cultivation, application of broad spectrum agrochemicals and excessive crop residue removal may continue to decrease soils inherent capacity to maintain health.

4. CONCLUSION

The results of this study demonstrate presence of *Trichoderma* within different land-use types with varying abundance, richness and diversity. The undisturbed lands, which represent low level of intensification, had the highest abundance, richness and diversity while irrigated intensively cultivated farmlands had the least of these parameters. This study clearly showed that soil disturbance and crop species influences the population structure of the soil *Trichoderma.*

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Alliance for Green Revolution in Africa. Africa Agriculture Status Report: Focus On Staple Crops. Nairobi, Kenya. 2013;204.

2. Köhl L, Oehl F, van der Heijden MGA. Agricultural practices indirectly influence plant productivity and ecosystem services through effects on soil biota. Ecol. Appl. 2014;24:1842–1853.
3. Lal R. Managing soils for a warming earth in a food-insecure and energy-starved world. Journal of Plant Nutrition and Soil Science. 2010;173:4–15.
DOI: 10.1002/jpln.200900290.
4. Lehman MR, Cambardella CA, Stott DE, Acosta-Martinez V, Manter DK, Buyer Jeffrey S, Maul JE, Smith JL, Collins HP, Halvorson JJ, Kremer RJ, Lundgren JG, Ducey TF, Jin VL, Karlen DL. Understanding and Enhancing Soil Biological Health: The Solution for Reversing Soil Degradation. Sustainability. 2015;7:988-1027.
DOI:10.3390/su7010988.
5. Food and Agriculture Organization of the United Nations. (2009). Food security and agricultural mitigation in developing countries: Options for capturing synergies. Rome, Italy.
Available:http://www.fao.org/docrep/012/i1318e/i1318e00.pdf
6. Nannipieri P, Ascher J, Ceccherini M T, Landi L, Pietra-mellara G, Renella G. Microbial diversity and soil functions. Eur J Soil Sci. 2003;54:655–70.
7. Mazzola M. Assessment and management of soil microbial community structure for disease suppression. Ann Rev Phytopathol. 2004;42:35–59.
8. Hagn A, Geue H, Pritsch K, Schloter M. Assessment of fungal diversity and community structure in agricultural used soils. Kerala, India: Research Signpost; 2002.
9. Widden P, Abitbol JJ. Seasonality of *Trichoderma* species in a spruce-forest soil. Mycologia. 1980;72:775-784.
10. Okoth SA, Okoth P, Wachira PM, Roimen H. Spatial distribution of *Trichoderma* spp. in Embu and Taita regions, Kenya. Trop. Subtrop. Agroecosyst. 2009;11:291–301.
11. Klein D, Eveleigh E. Ecology of *Trichoderma*. In *Trichoderma and Gliocladium*, C. P. Kubicek & G. E. Harman (Eds). London; Bristol, PA: Taylor & Francis. 1998;57-69.
12. Nikolajeva V, Petrina Z, Vulfa L, Alksne L, Eze D, Grantina L, Gaitnieks T, Lielpetere A. Growth and antagonism of *Trichoderma* spp. and conifer pathogen *Heterobasidion annosums*. I. *In vitro* at different temperatures. Adv Microbiol. 2012;2:295–302.
13. Poosapati S, Ravulapalli PD, Tippirishetty N, Vishwanathaswamy DK, Chunduri S. Selection of high temperature and salinity tolerant *Trichoderma* isolates with antagonistic activity against *Sclerotium rolfsii*. Springer Plus. 2014;3:641.
DOI:10.1186/2193-1801-3-641.
14. Lavelle P, Spain AV. Soil Ecology. Dordrecht; Boston: Kluwer Academic Publishers; 2001.
15. Domsch KH, Gams W, Anderson TH. Compendium of soil fungi. London; New York: Academic Press; 1980.
16. Gal-Hemed I, Atanasova L, Komon-Zelazowska M, Druzhinina SI, Viterbo A, Yarden O. Marine isolates of *Trichoderma* as potential halotolerant agents of biological control for arid-zone agriculture. Applied Environmental Microbiology. 2011; 77(15):5100–5109.
17. Gupta VK, Schmol M, Herrera-Estrella A, Upadhyay RS, Druzhinina I, Tuohy MG. Biotechnology and biology of *Trichoderma.* Elsevier B.V. Amsterdam, Netherlands. 2014;528.
18. Mathivanan N, Prabavathy VR, Vijayanandraj VR. The effect of fungal secondary metabolites on bacterial and fungal pathogens. 2008;129-140. In: P. Karlovsky (Ed.), Secondary Metabolites in Soil Ecology. Soil Biology, Springer-Verlag, Berlin- Heidelberg. 2009;14. ISBN 978-3-540-89620-3.
19. Bhale UN, Wagh PM, Rajkonda JN. Antagonistic confrontation of *Trichoderma* spp against fruit rots pathogens on Sapodilla (*Manilkara zapota* L.). Journal of Yeast and Fungal Research. 2013;4(1):5-11.
20. Mwangi MW, Monda EO, Okoth SA, Jefwa JM. Inoculation of tomato seedlings with *Trichoderma harzianum* and Arbuscular mycorrhizal fungi and their effect on growth and control of wilt in tomato seedlings. Brazilian Journal of Microbiology. 2011;42: 508-513.
21. Otadoh JA, Okoth SA, Ochanda J, Kahindi JP. Assessment of *Trichoderma* isolates for virulence efficacy on *Fusarium oxysporum* f. sp. *phaseoli.* Tropical and Subtropical Agroecosystems. 2011;13:99-107.
22. Siameto EN, Okoth S, Amugune NO, Chege NC. Antagonism of *Trichoderma harzianum* isolates on soil borne plant

pathogenic fungi from Embu District, Kenya. Journal of Yeast and Fungal Research. 2010;3:47-54.
23. Harman G, Howell CR, Viterbo A, Chet I. Lorito M. *Trichoderma* species-opportunistic, avirulent plant symbionts. Nature Reviews. 2004a;2:43–56.
24. Hoyos-Carvajal L, Orduz S, Bissett J. Genetic and metabolic biodiversity of *Trichoderma* from Colombia and adjacent neotropic regions. Fungal Genet Biol. 2009;46:615-631.
25. Sadfi-Zouaoui N, Hannachi I, Rouaissi M, Hajlaoui MR, Rubio MB, Monte E, Boudabous A, Hermosa MR. Biodiversity of *Trichoderma* strains in Tunisia. Can J Microbiol. 2009;55:154-162.
26. Sun RY, Liu ZC, Fu K, Fan L, Chen J. *Trichoderma* biodiversity in China. J Appl Genet. 2012;53:343-354.
27. McLean KL, Swaminathan J, Frampton CM, Hunt JS, Ridgway HJ, Stewart A. Effect of formulation on the rhizosphere competence and biocontrol ability of *Trichoderma atroviride* C52. Plant Pathology. 2005;54:212-218.
28. Samuels GJ. *Trichoderma*: systematics, the sexual state and ecology. Phytopathology. 2006;96:195–206.
29. Gams W, Bissett J. Morphology and identification of *Trichoderma*. In *Trichoderma* and *Gliocladium*. C. P. Kubicek & G. E. Harman (Eds). London; Bristol, PA: Taylor & Francis. 1998;3-31.
30. Tuomisto H. A diversity of beta diversities: Straightening up a concept gone awry. Part 1. Defining beta diversity as a function of alpha and gamma diversity. Ecography. 2010;33:2–22. DOI:10.1111/j.1600-0587.2009.05880.
31. Kubicek CP. Fungi and Lignocellulosic Biomass. Wiley Blackwell, UK Oxford. 2013;29-41.
32. Hoyos-Carvajal L, Bissett J. Biodiversity of *Trichoderma* in neotropis. In: Grillo, O., Venora G. (Eds). The Dynamical process of Biodiversity- Case studies of evolution and spatial distribution. Intech. 2011;303-320.
33. Cardoso-Lopes FA, Steindorff AS, Geraldine AM, Brandao RS, Monteiro VN, Junior ML, Guedes-Coelho AS, Ulhoa CJ, Siilva RN. Biochemical and metabolic profiles of *Trichoderma* strains isolated from common bean crops in the Brazillian Cerrado and potential antagonism against *Sclerotinia sclerotiorum*. Fungal Biology. 2012;116:815-824.
34. Kullnig C, Szakacs G, Kubicek CP. Molecular identification of *Trichoderma* species from Russia, Siberia and the Himalayas. Mycol. Res. 2000;104:1114-1125.
35. Jaklitsch WM. European species of Hypocrea part II, species with hyaline ascospores. Fungal Diversity. 2011;48:1-91.
36. Devi P, Prabhakaran N, Kamil D, Pandey P, Borah JL. Characterisation of Indian native isolates of *Trichoderma* spp. and assessment of their bio-control efficiency against plant pathogens. African Journal of Biotechnology. 2012;11(85):15150-15160.
37. Attitalla IH, Abdelrawaf SS, Omar KS, El-Komy HMA, Sarwar M. Occurrence and microbiological characteristics of *Trichoderma*in AL-Jabal Al-Akhdar region, Libya. Journal of Biological Sciences. 2012;12:209–217.
38. Bourguignon E. Ecology and diversity of indigenous *Trichoderma* species in vegetable cropping systems. PhD thesis. 2008;252.
39. Celar F. Influence of root exudates of different plant seedlings on mycelial growth of antagonistic fungi *Trichoderma species* and *Gliocladium roseum*. Zbornik-Biotehniske-Fakultete-Univerze-V-Ljubljani-Knaetisstvo. 2002;79:343-348.
40. Eastburn DM, Butler EE. Effects of soil moisture and temperature on the saprophyticability of *Trichoderma harzianum*. Mycologia. 1991;83:257-263.
41. Janusauskaite D, Kadziene G, Auskalniene O. The effect of tillage system on soil microbiota in relation to soil structure. Pol. J. Environ. Stud. 2013; 22(5):1387-1397.
42. Torensan S, Gomez E, Bonel B, Bisavo V, Montico S. Cellulolytic population dynamics in vertic soil under three tillage system in the Humid Pampa of Argentina. Soil Tillage Res. 1998;49:79-83.
43. Muniappan V, Muthukumar T. Influence of crop species and edaphic factors on the distribution and abundance of *Trichoderma* in Alfisol soils of southern India. Acta Bot. Croat. 2014;73(1):37–50.
44. Hjeljord L, Tronsmo A. *Trichoderma* and *Gliocladium* in biological control: an overview. In: Harman, G. E., Kubicek, C. P. (Eds), *Trichoderma* and *Gliocladium*, 2. Enzymes, biological control and

commercial applications. Taylor and Francis Ltd., London. 1998;131–151.
45. Kredics L, Antal Z, Manczinger L, Szekeres A, Kevei F, Nagy E. Influence of environmental parameters on *Trichoderma* strains with biocontrol potential. Food Technology and Biotechnology. 2003;47: 37–42.
46. Küçük C, Kivanç M. Isolation of *Trichoderma* spp. and determination of their antifungal, biochemical and physiological features. Turkish Journal of Biology. 2003;27:247–253.
47. Eastburn DM, Butler EE. Microhabitat characterization of *Trichoderma harzianum* in natural soil: Evaluation of factors affecting distribution. Soil Biology and Biochemistry. 1988;20:547–553.
48. Simon A, Sivasithambaram K, Macnish GC. Effect of application of soil nitrogenous fertilizers and lime on biological suppression of *Gaeumannomyces graminis* var. *tritici*. Transactions of the British Mycological Society. 1988;91:287–294.
49. Wu T, Chellami DO, Graham JH, Rosskopf EN. Assessment of fungal communities in soil and tomato roots subjected to diverse land and crop management systems. Soil Biology & Biochemistry. 2008;40:1967-1970.
50. Geisseler D, Scow KM. Long-term effects of mineral fertilizers on soil microorganisms: A review. Soil Biology & Biochemistry. 2014;75:54–63.
51. Sariah M, Choo CW, Zakaria H, Norihan MS. Quantification and characterization of *Trichoderma* spp. from different ecosystems. Mycopathology. 2005;159: 113-117.
52. Kladivko EJ. Tillage systems and soil ecology. Soil Tillage Res. 2001;61:61–76.
53. Grayston SJ, Wang S, Campbell CD, Edwards AC. Selective influence of plant species on microbial diversity in the rhizophere. Soil Biology and Biochemistry. 1998;30:36–78.
54. Ibekwe AM, Kennedy AC, Frohne PS, Papriernik SK, Yang CH. Microbial diversity along a transect of agronomic zones. FEMS Microb. Ecology. 2002;39: 183–191.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/9947