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Effects of Land-Use Intensification on Distribution and Diversity of *Fusarium* Species in Machakos County, Kenya

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Abstract

Land-use intensification has a significant influence on occurrence of soil microorganisms. The effect of this phenomenon on *Fusarium* species is poorly characterized. One hundred soil samples were obtained from 3 replicated land- use types (LUT) in Mwala and Kauti irrigation regions in Machakos County. These included two intensive land-uses under irrigation and rain-fed agriculture and undisturbed lands. Mwala irrigated lands were divided into four blocks based on history of cultivation. Using soil dilution plate technique, 1,546 isolates of *Fusarium* were recovered and identified into twelve species namely; *F. oxysporum*, *F. solani*, *F. nygamai*, *F. equiseti*, *F. chlamydosporum*, *F. beomiforme*, *F. verticillioides*, *F. proliferatum*, *F. acuminatum*, *F. compactum*, *F. semitectum*, and *F. merismoides*. *Fusarium oxysporum* was the most abundant and diverse *Fusarium* species. *Fusarium semitectum*, *F. compactum* and *F .merismoides* had the least distribution being isolated from only one LUT. *Fusarium beomiforme* and *F. acuminatum* were recovered from irrigated farmlands only while *F. verticillioides*, *F. proliferatum* and *F. acuminatum* were restricted to disturbed lands only. The difference in abundance of *Fusarium* between the three LUTs was significant (P = 0.047) with irrigated lands having the highest abundance. Mwala block A had the highest abundance, richness and diversity of *Fusarium*. Lands with a higher intensity of disturbance had a higher abundance and richness of *Fusarium* than the less undisturbed lands. This may have severe implication on crop production as most species of *Fusarium* isolated are pathogenic. Sustainable ways of controlling these potential crop pathogens should be sought.

Keywords: biodiversity, distribution *Fusarium*, intensification, land-use

1. Introduction

Fusarium is a large and diverse genus of filamentous fungi classified in the Order Hypocreales of the Phylum Ascomycetes. This form-genus was first described by Link in1809. Later, the genus *Fusarium* was defined by Wollenweber and Reinking (1935) based on morphological and cultural characteristics. However, *Fusarium* is a polyphyletic genus which includes over 50 species and has cosmopolitan distribution in the air, soil and in association with many plants (Alexopoulos et al., 1996; Leslie et al., 2006). Many *Fusarium* species cause diseases of economic importance in crops. Besides causing air-borne respiratory infections in human, some species of *Fusarium* may also cause a range of opportunistic infections such as keratomycosis (Mselle, 1999), onychomycosis (Godoy et al., 2004), pulmonary infections (Gorman et al., 2006) and endophthalmitis (Goldblum et al., 2000) in immune-compromised humans. *Fusarium* species also produce a wide array of mycotoxins. These are fumonisins, beauvericin, moniliformin, zearalenone, nivalenol, deoxynivalenol, fusaproliferin, and trichothecene in cereals (Blaney & Dodman, 2002). These mycotoxins are responsible for allergies, growth defects and cancer in humans and domestic animals (Broomhead et al., 2002). It is known that *Fusarium* is a cosmopolitan genus and a natural soil fungus (Nurhazrati et al., 2012). In agricultural soils, *Fusarium* is a typical genus. Previous studies in Kenya on *Fusarium* prevalence in soils indicate that it is a highly distributed and diverse genus (Kedera et al., 1999; Maina et al., 2009). This fungus was found to be prevalent in agricultural soils of Malaysia, with *Fusarium oxysporum* being the most abundant species (Siti et al., 2012).

The predominant interest in the genus *Fusarium* is its role as plant pathogens (Booth, 1971). *Fusarium* species cause a variety of serious plants diseases. These include vascular wilts, cankers, rots of seed, fruit, root and stem, and blights in a wide range of economically important crops. This is due to the fact that *Fusarium* chlamydospores, conidia and hyphae are distributed widely in cultivated soil and soil debris (Bolkan et al., 1979). These propagules gain entry into the plant through cut surfaces of seeds, damaged roots and stem tissues of young and stressed plants. Infection through wounds caused by insects can also act as point of entry, therefore, causing diseases to susceptible plants (Leslie et al., 2006).

Fusarium species are able to survive in the soil for long periods of time as chlamydospores (Vakalounakis & Chalkias, 2004). These are resting spores of *Fusarium* species produced in the soil during periods of unfavorable conditions (Leslie et al., 2006). Many *Fusarium* species also exist as harmless saprobes in the soil while others establish long-term associations with crop plants as endophytes (Bacon & Hinton, 1996). A high diversity index of soil *Fusarium* species is important for their involvement in soil structure formation; decomposition of organic matter; toxin removal; and the cycling of carbon, nitrogen, phosphorus, and sulphur (Garbeva et al., 2004). However, the presence of diverse species of *Fusarium* in agricultural soil may lead to disease infection of susceptible plants (Silvestro et al., 2013). Apparently the cultivated soil is the most important source of *Fusarium* spores. Moreover, *Fusarium* inoculum is spread by air, infected debris and soils (Summerell et al., 2010).

The rapid increase in human population in Kenya has resulted in increased demand for food leading to rapid conversion of natural vegetation lands to agricultural lands. Some expansions have involved clearing natural forests and grasslands. Being largely semi-arid, Kenya experiences shortage of arable land leading to increased fragmentation and intensification of the available arable land. These land-use practices have major effects on soil biodiversity including increase in soil plant pathogenic species especially of *Fusarium* (Foley, 2005; Luque et al., 2005; Siti et al., 2012; Okoth et al., 2013). Silvestro et al. (2013) reported that the prevalence of *Fusarium* in agricultural soils is largely determined by plant species and soil depth. Prevalence of *Fusarium* in agricultural soil is a threat to the productivity of agricultural crops as all crops have a certain *Fusarium* species that infect them. Therefore, this study sought to determine the effect of land-use intensification on the occurrence, distribution and diversity of *Fusarium* species in Kenyan soils. The inventory obtained will form basis for comparison studies and possible policy formulations in an endeavor to produce food sustainably.

2. Materials and Methods

2.1 Study Area

The study was carried out in Kabaa irrigation scheme, Mbiuni location, Mwala Sub-county of Machakos County that experiences arid and semi-arid type of climate and also the temperature varies from 6 ^{o}C to 29 ^{o}C. Two regions were selected: Mwala and Kauti irrigation schemes. These areas were selected due to variations in land-use which includes intensive irrigated and rain-fed agriculture as well as undisturbed lands in the vicinity for comparison. In each region, soils were sampled from the 3 replicated LUTs. Mwala is located in lower midland zone 4, with cambisol soils. The main crops cultivated are French bean, tomato, onion, banana, kale, cabbage and passion fruit. The scheme is divided into four blocks (A to D) with A being the oldest block while D is the most recent. Kauti irrigation scheme lies in the upper midland zone 4 with alfisols and acrisols soils. The main crops grown here are French bean, kale, tomato, maize and coffee.

2.2 Soil Sampling

Soil samples were collected from 3 major LUTs; from irrigated agricultural and rain-fed agricultural farmlands and from undisturbed lands. This was replicated in the two regions of Mwala and Kauti irrigation schemes. 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 are composed of native grasses and deciduous thorn bushes made of *Commiphora/Sanseveria* association. At each sampling point, 12 subsamples were collected from the top 20 cm of soil (Figure 1).

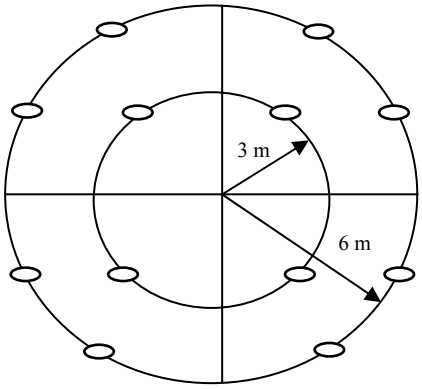

Figure 1. Schematic representation of the twelve soil sampling points which comprised one main sampling point

Soil samples were collected using a sterilised soil auger and mixed thoroughly before obtaining 100 g from this sample. To avoid cross-contamination between sampling points, the auger was sterilized between sampling points by using cotton wool soaked in 70% ethanol. The samples were put in paper bags and transported in the laboratory where they were stored at 5 ^{o}C awaiting further analysis. The soil samples were air-dried at room temperature (27±1 ^{o}C) for 5 days and ground and then sieved with 0.5 mm sieve to separate larger particles. These soil samples were used for isolation and quantification of *Fusarium*.

2.3 Isolation of Fusarium from the Soil

Soils were assayed using serial dilution plating method as described by Burgess et al. (1988) with 0.1% Tap Water Agar (Brayford, 1993). *Fusarium*-selective PCNB-Peptone Agar (PPA) media were used to recover *Fusarium* isolates from the soil. From each of the of soil sample, 10 g of air-dried soil were removed and added to 90 ml of sterile 0.1% Tap Water Agar. The mixture was vigorously agitated (200 rpm for 60 s on a Lab-Line Orbital shaker, Melrose Park, IL) and 10 ml of the 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 (Burgess et al., 1988). 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.

2.4 Sub Culturing, Purification and Identification of Fusarium Species

Colonies from PPA media were transferred to Spezieller Nahrstoffarmer Agar (SNA) media to form distinctive colonies and sporulation and incubated at 25 ^{o}C for 5 days (Leslie & Summerell, 2006). 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% plates. Germlings on 2% Tap Water Agar (TWA) were then sub cultured on SNA, Carnation-Leaf-Agar (CLA) and Potato-Dextrose-Agar (PDA) media, for growth and identification (Leslie & Summerell, 2006). PDA cultures were used to assess pigmentation and gross colony morphology. Cultures grown on SNA were evaluated for microconidia and for chlamydospores.

All the pure isolates sub cultured on PDA, CLA and SNA were incubated for ten to twenty days at 25 ^{o}C under fluorescent lamps (Sylvania cool white tubes) with a 12 h photoperiod. *Fusarium* species were identified by morphological characteristics (Brayford, 1993; Burgess et al., 1988; Leslie & Summerell, 2006; Nelson et al., 1983). After identification, the single spore cultures were preserved in agar slants of SNA in screw cap bottles at 4 ^{o}C and also in sterilized soil in screw cap bottles.

2.5 Statistical Analyses

The data obtained showing occurrence, richness and diversity of *Fusarium* species in the soil in relation to LUTs were analyzed using GenStat computer package, discovery edition. Data were first standardized before analyses to take into account the difference in sample numbers between the different LUTs. Data obtained on abundance were transformed using logarithm for normality. Analysis of variance was used to determine the effects of different land uses on occurrence, richness and diversity of *Fusarium* species. Diversity was calculated using

Shannon`s diversity index (H'). Significance was evaluated at $P < 0.05$ for all analyses. Means found to be significantly different were separated using Tukey test at $P < 0.05$.

3. Results

A total of 1,546 *Fusarium* isolates were recovered during the study. The identification of these isolates resulted into 12 *Fusarium* species (Table 1). *Fusarium oxysporum* was the most abundant *Fusarium* species, with a frequency of isolation of 60.9%, followed by *F. solani* at 16.3%. The two accounted for 77.2% of all *Fusarium* isolates recovered. *Fusarium merismoides* had the least isolation frequency at 0.1% and was only isolated from Mwala rainfed farms (Table 1). Results further revealed that *F. oxysporum* and *F. solani* accounted for 97.4% of all fusaria isolated from the Mwala irrigation blocks.

Table 1. Frequency of isolation of *Fusarium* species from different Land Use Types

***Fusarium* species**	**Proportion (%) per land use type**						**Overall proportion (%)**
	Mwala irrigated	**Mwala rainfed**	**Mwala undisturbed**	**Kauti irrigated**	**Kauti rainfed**	**Kauti undisturbed**	
F. oxysporum	75.9	38.9	40	22.2	27.3	18.2	**60.9**
F. solani	21.5	7.7	0	0	18.2	18.2	**16.3**
F. nygamai	0	24.0	13.3	2.2	9.1	9.1	**6.8**
F. equiseti	0	16.8	0	2.2	4.5	36.3	**5.0**
F. chlamydosporum	0	9.7	6.7	2.2	22.7	18.2	**3.5**
F. beomiforme	0.4	0	0	51.1	0	0	**3.0**
F. verticillioides	0.8	2.4	0	6.8	0	0	**1.5**
F. proliferatum	1.0	0	0	2.2	18.2	0	**1.3**
F. acuminatum	0.4	0	0	11.1	0	0	**0.9**
F. compactum	0	0	26.7	0	0	0	**0.5**
F. semitectum	0	0	13.3	0	0	0	**0.2**
F. merismoides	0	0.5	0	0	0	0	**0.1**
Frequency of isolation (%)	**63.4**	**25.3**	**1.8**	**5.5**	**2.7**	**1.3**	**100%**

The difference in abundance of *Fusarium* between the LUTs was significant ($P = 0.047$). The *Fusarium* Log (Abundance +1) for the irrigated, rainfed and undisturbed were, 3.49, 2.8 and 1.96, respectively (Figure 2). Lands with a higher intensity of disturbance had a higher abundance of soil *Fusarium* than the undisturbed farmlands as this was recorded in both Mwala and Kauti regions (Figures 3 and 4).

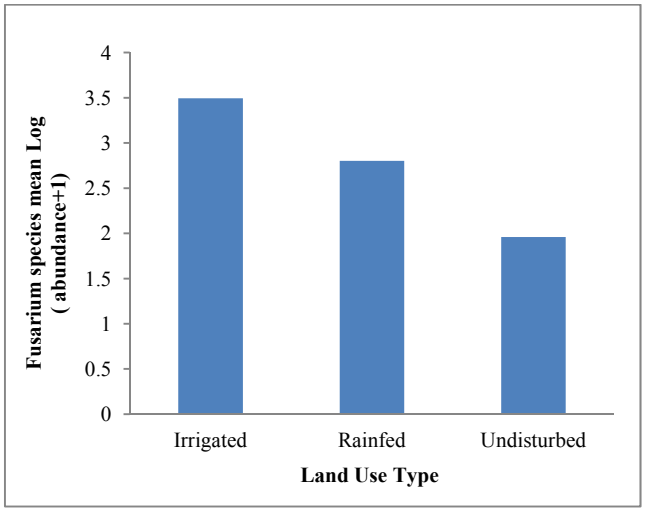

Figure 2. *Fusarium* mean Log (Abundance+1) for different LUTs

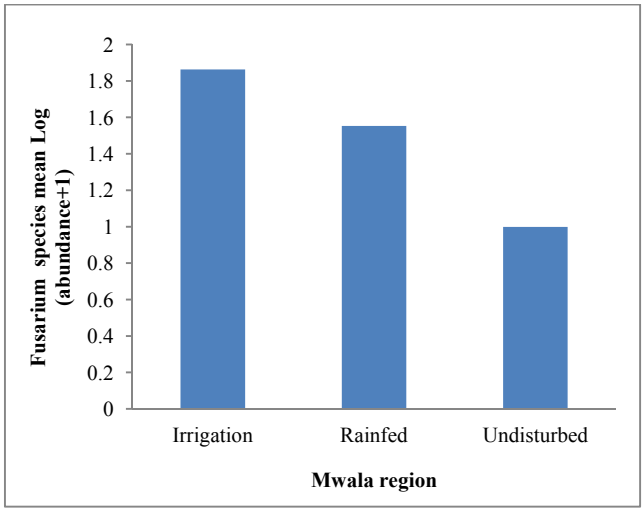

Figure 3. *Fusarium* mean Log (Abundance +1) within Mwala region

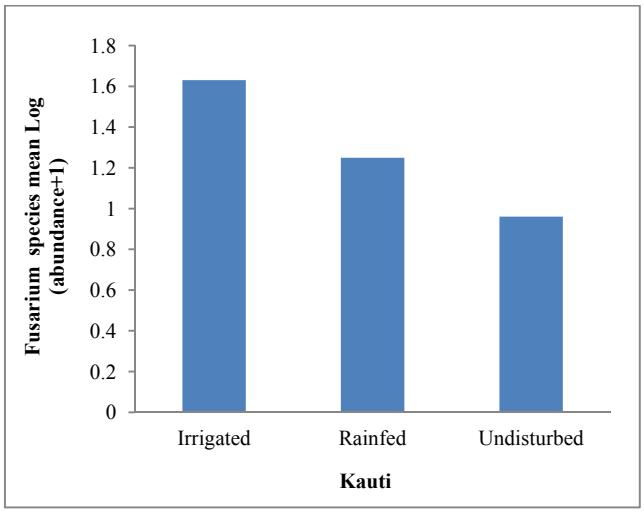

Figure 4. *Fusarium* mean Log (Abundance +1) within Kauti region

The relationship between LUT and abundance of soil *Fusarium* was clear. This was evidenced by the greater numbers of *Fusarium* recovered from irrigated LUT, followed by rainfed LUT, with undisturbed having least soil *Fusarium* in both schemes. Specifically, the difference in abundance of *Fusarium* species within Mwala irrigation blocks were not significant ($P = 0.356$). Block A had a higher abundance of *Fusarium* compared to the rest (Figure 5). Block A has a longer history of disturbance than the other blocks and it accounted for 63.6% of *Fusarium* isolates from Mwala irrigated lands (Table 2). Block D which is a relatively recent irrigation block had the least isolation frequency of 2.1%.

Table 2. Frequency of isolation of *Fusarium* species in Mwala irrigation blocks

***Fusarium* spp.**	**% of isolation in the irrigation blocks**				
	A	**B**	**C**	**D**	**%**
F. oxysporum	72.3	82.9	82.1	72.7	**75.9**
F. solani	25	13.8	16.1	3.3	**21.4**
F. nygamai	0	0	0	0	**0**
F .equiseti	0	0	0	0	**0**
F. chlamydosporum	0	0	0	0	**0**
F. beomiforme	0.3	0.8	0	0	**0.4**
F. verticillioides	0.9	0.8	0	0	**0.8**
F. proliferatum	0.9	1.6	1.8	0	**1.1**
F. acuminatum	0.6	0	0	0	**0.4**
F. compactum	0	0	0	0	**0**
F. semitectum	0	0	0	0	**0**
F. merismoides	0	0	0	0	**0**
%	**63.6**	**23.6**	**10.7**	**2.1**	**100**

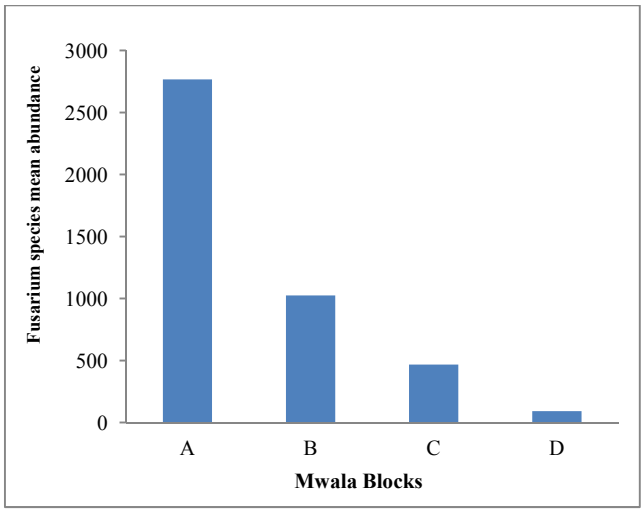

Figure 5. *Fusarium* mean Log (Abundance +1) within Mwala irrigation blocks

Among the *Fusarium* species, *F. oxysporum* had the widest distribution occurring in all the LUTs under study. *Fusarium nygamai*, *F. equiseti* and *F. chlamydosporum* also had a wide distribution. *Fusarium beomiforme* and *F. acuminatum* were only recovered from irrigated farmlands while *F. semitectum* and *F. compactum* were only isolated from undisturbed soils. Isolates of *F. beomiforme*, *F. verticillioides*, *F. proliferatum* and *F. acuminatum* were only isolated from disturbed land use during this study while *Fusarium merismoides* was only isolated from land under rain-fed land use.

Results indicated that irrigated farmlands had the highest *Fusarium* species mean richness while undisturbed lands had the least richness. This indicated that intensity in land use had an influence on *Fusarium* species richness. Although there is no significant difference in *Fusarium* species richness across the LUTs ($P = 0.825$), the intensively cultivated lands had higher species richness than the undisturbed farmlands (Figure 6).

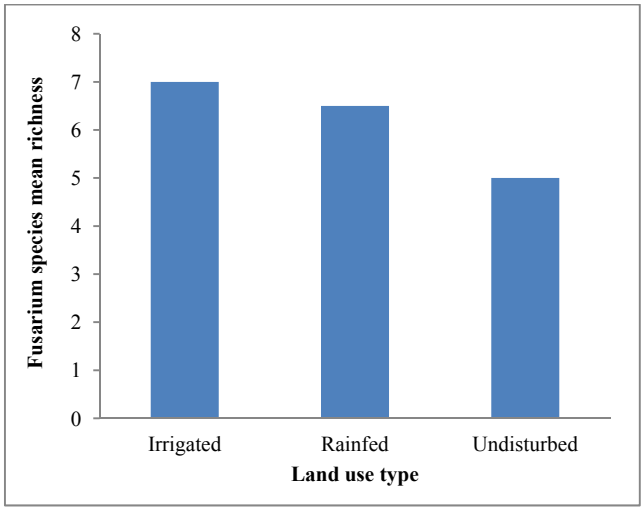

Figure 6. *Fusarium* species mean richness for different LUTs

The undisturbed lands had the lowest *Fusarium* species mean richness in both Mwala and Kauti regions (Table 3). The irrigated land use in Kauti had the highest mean richness followed by Mwala rain-fed land use (Table 3). Mwala region had a lower *Fusarium* mean richness than Kauti. The relationship on history of cultivation and richness was clear among Mwala irrigation blocks, with block A having the highest species richness, followed by block B. Block D, being the most recent irrigation block had the lowest richness (Figure 7). However, the difference in species richness between these irrigation blocks of Mwala was not significant ($P = 0.353$).

Table 3. *Fusarium* species mean richness for different land use types.

Land use type	***Fusarium* species mean richness**	
	Mwala	**Kauti**
Irrigated	6	8
Rainfed	7	6
Undisturbed	5	5

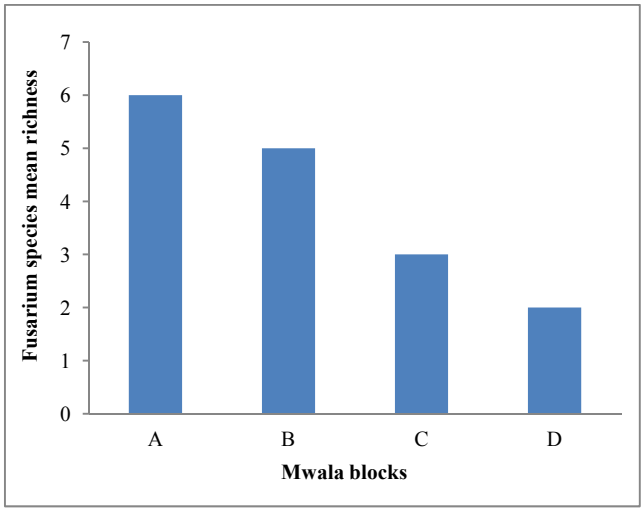

Figure 7. *Fusarium* species mean richness within Mwala irrigation blocks

During this study, the diversity of *Fusarium* species in different LUTs did not show any significant difference ($P = 0.063$), neither was there a relationship observed between the intensity of land-use and *Fusarium* species

diversity. Overall, rainfed land-use had the highest diversity followed by undisturbed lands (Figure 8). This trend was evident in both Mwala and Kauti regions. In comparison, Kauti rain-fed land-use had the greatest *Fusarium* species mean index (H' = 1.669), followed by Mwala rain-fed land-use (H' = 1.548) while Mwala irrigated land-use had the least mean Shannon index (H' = 0.671).

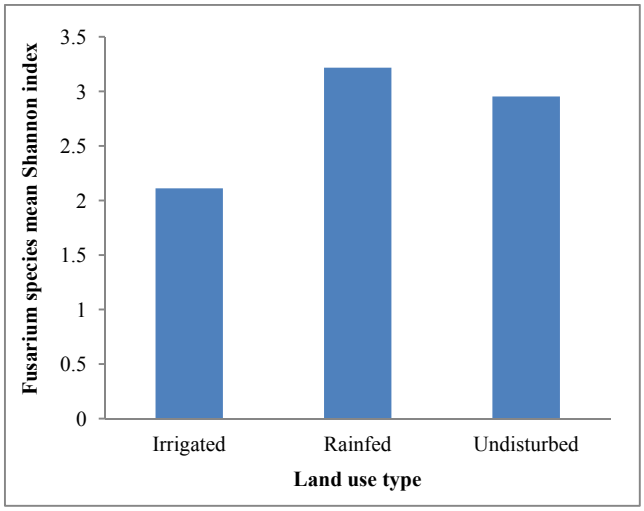

Figure 8. *Fusarium* species mean Shannon indices for different LUTs

Results further indicated that the history of cultivation had no influence on diversity of *Fusarium* species. Within Mwala irrigation blocks, block A had the highest diversity, followed by D while C was least diverse (Figure 9).

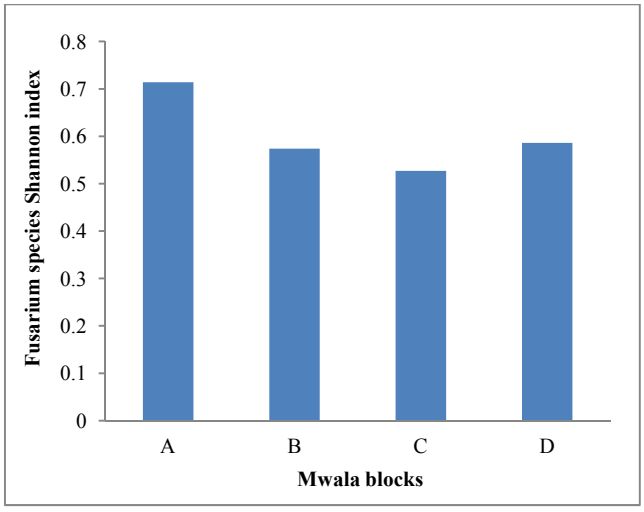

Figure 9. *Fusarium* species mean Shannon indices within Mwala irrigation blocks

4. Discussion

This study has revealed prevalence of *Fusarium* species in the soils of Kabaa irrigation scheme where a total of 1,546 isolates of *Fusarium* species were obtained and characterized into 12 *Fusarium* species. These species are widely distributed in the irrigated, rainfed and disturbed soils in the study area. The results are in iIn agreement with this findings Silvestro et al. (2013) noted that *Fusarium* spp. is a cosmopolitan genus and a natural soil fungus. Members of this genus are ubiquitous in soil and have been isolated from various soil types in tropical and temperate regions, from desert soils to artic and alpine soils (Latiffah et al., 2007; Summerell et al., 2010). However, the majority of *Fusarium* species are recovered in cultivated soils especially near the soil surface. Wakelin et al. (2008) reported that *Fusarium* species occur widely in cultivated soils and is often associated with

plant roots either as parasites or saprophytes. The abundance of these species generally resembles that reported in South Africa (Rheeder & Marasas, 1998).

Earlier studies of *Fusarium* in Africa and Asia showed variable numbers and species composition. In their study Latiffah et al. (2007) identified four *Fusarium* species, namely, *F. solani*, *F. equiseti*, *F. semitectum* and *F. oxysporum*. In other studies in Lesotho, Nigeria and Zimbabwe have shown diverse species occurrence: *F. oxysporum*, *F. equiseti*, *F. solani*, *F. moniliforme*, *F. compactum*, *F. nygamai*, and *F. chlamydosporum* (Fawole & Olowonihi, 2005; Nwanwa & Nelson, 1993). A similar study of soils of South Africa showed the presence of nineteen species. These were *F. chlamydosporum*, *F. merismoides*, *F. lateritium*, *F. culmorum*, *F. compactum*, *F. dlamini*, *F. poae*, *F. proliferatum*, *F. verticillioides*, *F. scirpi*, *F. polyphialidicum*, *F. graminearum*, *F. sambucinum*, *F. napiforme*, *F. oxysporum*, *F. equiseti*, *F. semitectum*, *F. nygamai* and *F. solani*. Of these *F. oxysporum*, *F. equiseti*, *F. semitectum*, *F. nygamai* and *F. solani* were the most frequently isolated (Jeschke et al., 1990). *Fusarium semitectum* and *F. equiseti* were commonly isolated from soil as reported by Burgess et al. (1988) and Leslie et al. (1990, 2006), and most probably exist as soil inhabitants. Both species are not regarded as important plant pathogens although the species have been reported to cause diseases on several crops (Elmer, 1996). A previous study in soils of Kenya showed the occurrence of 26 species of *Fusarium* under different land use systems (Maina et al., 2009). The study revealed that *Fusarium oxysporum* was the most abundant and distributed species. These results are similar to those of the current study. This species could probably be highly adapted for competition as well as having a wide host range (Edel et al., 2001; Nelson et al., 1981). The difference in composition and abundance of soil *Fusarium* could be attributed to differences in type of plants grown, soil characteristics, as well as land management practices (Chehri, 2011).

This study indicated a high prevalence of *Fusarium oxysporum* being isolated from all LUTs. In their study, Maina et al. (2009) reported similar results, where *F. oxysporum* was the most prevalent species. Siti et al. (2012) also reported high prevalence of *Fusarium* species in Malaysia. In their study on diversity of *Fusarium* in agricultural lands, it was revealed that *F. oxysporum* was the most prevalent species at 26.2% followed by *F. semitectum* and *F. solani* at 24 and 21.3%, respectively. The prevalence of *F. oxysporum* fungus especially in cultivated lands in this study is an indicative of status of soil health. Members of this fungus have been reported as a serious pathogen on various plants and the prevalence of this fungus in the study area is a cause for concern. The plant pathogenic representatives of *Fusarium oxysporum* are involved in a variety of plant diseases such as vascular wilts, damping-off, crown rots and root rots (Jarvis & Shoemaker, 1978; Summerell & Rugg, 1992). In addition, *F. solani* was the second most prevalent species isolated in this study and was recovered in all the LUTs. It is a common soil-borne fungi and a pathogen to many agriculture crops such as citrus, pepper, and beans, (Fletcher & Karen, 2007; Nemec, 1987). Several studies have revealed that this species is widely distributed in numerous native soils such as in sub tropical, semi-arid and grassland soils (Burgess & Summerell, 1992) and desert soil (El Gindy & Saad, 1990). Therefore, in this study, it was not surprising that *F. solani* was the second most frequent species isolated from the study area. However, in a study covering Malaysian highlands, *F. solani* was the most abundant species at 66.1% of all isolates followed by *F. graminearum* and *F. oxysporum* at 8.5 and 7.8%, respectively (Nurhazrati et al., 2012). This can be explained by the low temperatures of the highlands as well as the type of plants growing in these areas.

In this study, *F. merismoides* had the lowest abundance and the most restricted distribution. These results are in agreement with those of Silvestro et al. (2013) who reported that this species had a restricted distribution being isolated only from 5-10 cm soil layer from the rotation of winter agriculture. Jeschke et al. (1990) also observed low frequency of *F. merismoides* in soil samples collected from different altitudes in Southern Africa. The reason for low abundance and distribution of this species could probably be due to unfavovarable soil conditions. Leslie and Summerell (2006) suggested that *F. merismoides* is a fungal soil saprophyte, but has the potential to cause infections in plants if the environmental conditions are appropriate. Bateman and Murray (2001) observed that the frequency of this species in the soil increased under dry conditions, suggesting that the presence of a mucilaginous matrix produced by this fungal species may favor its survival and ability to compete in dry conditions (Louis & Cooke, 1983).

Results of this study further revealed that the soil abundance of *Fusarium* was related to the LUT. The abundance of soil *Fusarium* was positively influenced by intensity of disturbance. Farmlands with a higher intensity of disturbance had higher abundances of *Fusarium* while the undisturbed farmlands had the least abundance. These observations were replicated for both regions under study. These results are similar to those reported by Maina et al. (2009) who reported a higher abundance of *Fusarium* in disturbed lands. These results also correlate well with the survey carried out by Marasas et al. (1988) which revealed very low populations of *Fusarium* species in undisturbed indigenous sites. Bushula (2008) isolated only 122 *Fusarium* isolates from

native soils of Western Cape that were grouped into only 3 species. The results of the current study agree with previous reports from other authors, who observed that *Fusarium* genus is one of the most abundant fungi in agricultural soils and less abundant in undisturbed lands (Marasas et al., 1988; Thorn, 1997).

Disturbance of the soil through tillage leads to fragmentation of fungal hyphae which acts as propagules. Tillage may also help in dispersal of *Fusarium* propagules (Steinkellner & Langer, 2005). It also opens up the soil to aeration and hence supports physiological activities of *Fusarium* in the soil. It creates spaces through which water may percolate, hence aiding in dispersal of propagules. This can explain the high number of fusaria in cultivated under irrigation. According to Salas and Stack (1991), the method of tillage may not only affect the composition of soil *Fusarium* but also the abundance of species. That soil characteristics affect the abundance of soil fusaria has been confirmed (Maina et al., 2009; Wei et al., 2012). Cultivation of crops in the study area may involve use of organic and inorganic fertilizers, which may have an impact on abundance of soil fusaria (Maina et al., 2009). Long-term application of these elements in the soil will therefore have a bearing on abundance of soil fusaria. This may also account for higher abundance of this fungal group in agricultural land than the undisturbed soils. This study also indicated that there is low occurrence of *Fusarium* species in undisturbed soils. This could be as a result of suppression by other predominant saprophytic fungi present or that the fungus is selected against through lack of suitable host in these ecosystems.

The abundance of soil *Fusarium* was also positively influenced by the length in time of disturbance. This trend was clearly shown in Mwala irrigated blocks (Figure 5). Longer history of cultivation may favor proliferation of soil *Fusarium* due to prevalence of suitable host and conducive environmental conditions. Continuous cultivation ensures suitable substrates in the soil for the fungus. Wakelin et al. (2008) suggested that repeated incorporation of stubble into the soil after crop harvest could account for sustained higher populations of *Fusarium* species in the soil. *Fusarium* is a cellulolytic fungus and the stubble incorporation could increase fungal development and favor the breakdown of carbon and nitrogen source incorporated into the soil (Collins et al., 1990). Similar results were observed by Marasas et al. (1988) and Fernández et al. (2008) who showed that the presence of *F. acuminatum*, *F. equiseti* and *F. poae* could be related with the repeated incorporation of oilseed crops in the field sequence. They concluded that change in the structure of *Fusarium* community could be produced by changing type of crop stubble incorporated in the soil.

The results further revealed that *Fusarium* richness was positively related to disturbance. The most disturbed lands had the highest *Fusarium* richness. This was clearly demonstrated in both Mwala and Kauti regions. The results are in agreement with those of Nesci et al. (2006). Disturbance increases and sustains a higher richness of fungal species due to improved sources of nutrients and suitable growth environments. Richness also correlated positively with history of disturbance as reflected in Mwala irrigation blocks. The oldest block had the highest *Fusarium* richness. The results of this study further indicated that diversity between studied farms did not differ significantly. However, rain-fed land-use type had the highest diversity. This could be explained by the diversity of plants grown, soil characteristics and the effect of disturbance. Difference in soil properties and the crop types grown have been shown to affect the occurrence and recovery of *Fusarium* species (Burgess et al., 1988; Inam-Ul-Haq et al., 2009; Larkin & Fravel, 2002; Senthilkumar et al., 2011).

5. Conclusion

The study provides the baseline information on the occurrence, diversity and distribution of *Fusarium* in various land-use systems. The influence of land-use on the occurrence of this fungus is evident. The more disturbed farmlands had the highest abundance, richness and diversity of *Fusarium* species. Similarly, the lands with a longer history of cultivation had the higher abundance, richness and diversity of *Fusarium* species. Differences in abundance and distribution among *Fusarium* species were observed with *F. oxysporum* being the most predominant and with a cosmopolitan distribution. Enhanced population and diversity of *Fusarium* species in agricultural soils could impact negatively on crop health and consequently on production of food for humans and animals. Sustainable ways of managing this highly crop pathogenic fungus should therefore be explored.

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References

Alabouvette, C. (1999). *Fusarium* wilt suppressive soils: An example of disease suppressive soils. *Australasian Plant Pathology, 28*, 57-64. http://dx.doi.org/10.1071/AP99008

Alexopoulos, C. J., Mims, C. W., & Blackwell, M. (1996). *Introductory Mycology* (4th ed., p. 868). New York: John Wiley & Sons, Inc. Retrieved from http://trove.nla.gov.au/version/46511427

Amir, H., & Alabouvette, C. (1993). Involvement of soil abiotic factors in the mechanisms of soil suppressiveness of Fusarium wilts. *Soil Biology and Biochemistry, 25*, 157-164. http://dx.doi.org/10.1016/0038-0717(93)90022-4

Bacon, C. W., & Hinton, D. M. (1996). Symptomless endophytic colonisation of maize by *Fusarium moniliforme*. *Canadian Journal of Botany, 74*, 1195-1202. http://dx.doi.org/10.1139/b96-144

Bateman, G. L., & Murray, G. (2001). Seasonal variation in populations of *Fusarium* species in wheat-field soil. *Applied Soil Ecology, 18*, 117-128. http://dx.doi.org/10.1016/S0929-1393(01)00158-5

Blaney, B. J., & Dodman, R. L. (2002). Production of zearalenone, deoxynivalenol, nivalenol, and acetylated derivatives by Australian isolates of *Fusarium graminearum* and *F. pseudograminearum*in relation to source and culturing conditions. *Australian Journal of Agricultural Research, 53*, 1317-1326. http://dx.doi.org/10.1071/AR02041

Booth, C. (1971). *The genus Fusarium* (p. 237). Commonwealth Mycological Institute, Kew, Surrey, England. Retrieved from http://trove.nla.gov.au/version/27039116

Bolkan, H. A., Dianese, J. C., & Cupertino, F. P. (1979). Survival and colonization potential of *Fusarium moniliforme* var. *subglutinans* in soil. *Phytopathology, 69*, 1298-1301. http://dx.doi.org/10.1094/Phyto-69-1298

Brayford, D. (1993). *The identification of Fusarium species* (p. 119). CAB International, UK.

Broomhead, J. N., Ledoux, D. R., Bermudez, A. J., & Rottinghaus, G. E. (2002). Chronic effects of moniliformin in broilers and turkeys fed dietary treatments to marketage. *Avian Diseases, 46*, 901-908. http://dx.doi.org/10.1637/0005-2086(2002)046%5B0901:CEOMIB%5D2.0.CO;2

Burgess, L. W., Liddell, C. M., & Summerell, B. A. (1988). Laboratory manual for *Fusarium* research (2nd ed., p. 156). University of Sydney, Sydney.

Burgess, L. W., & Summerell, B. A. (1992). Mycogeography of Fusarium: Survey of Fusarium species from subtropical and semiarid grassland soils from Queensland Australia. *Mycological Research, 96*(9), 780-784. http://dx.doi.org/10.1016/S0953-7562(09)80448-6

Bushula, V. S. (2008). *Native Fusarium species from indigenous Fynbos soils of the Western Cape* (MSc. Thesis, p. 197). Stellenbosch University. Retrieved from http://hdl.handle.net/10019.1/2437

Chehri, K., Salleh, B., Yli-Mattila, T., Reddy, N., & Abbasi, S. (2011). Molecular characterisation of pathogenic *Fusarium* species in cucurbit plants from Kermanshah province, Iran. *Saudi Journal of Biological Sciences, 18*(4), 341-35. http://dx.doi.org/10.1016/j.sjbs.2011.01.007

Edel, V., Steinberg, C., Gautheron, N., Recorbet, G., & Alabouvette, C. (2001). Genetic diversity of *Fusarium oxysporum* populations isolated from different soils on France. *FEMS Microbiology Ecology, 36*, 61-71. http://dx.doi.org/10.1111/j.1574-6941.2001.tb00826.x

El Gindy, A. A., & Saad, R. R. (1990). Fungi of virgin and cultivated soil of Salhiah Desert, Egypt. *Zentralbl Mikrobiol,* 145(7): 547-551.

Elmer, W. H. (1996). *Fusarium* fruit rot of pumpkin in Connecticut. *Plant Disease, 80*, 131-135. http://dx.doi.org/10.1094/PD-80-0131

Fawole, O. B., & Olowonihi, E. T. (2005). Distribution of fungi and bacteria in the soils of the University of Ilorin Teaching and Research Farm. *Journal of Agricultural Research, 4*, 218-227.

Fernández, M. R., Huber, D., Basnyat, P., & Zentner, R. P. (2008). Impact of agronomic practices on populations of *Fusarium* and other fungi in cereal and non cereal crop residues on the Canadian Prairies. *Soil Till. Res., 100*, 60-71. http://dx.doi.org/10.1016/j.still.2008.04.008

Fletcher, J. T., & Karen, L. L. (2007). A stem rot of tomato caused by *Fusarium merismoides*. *Plant Pathology, 34*(3), 443-445. http://dx.doi.org/10.1111/j.1365-3059.1985.tb01387.x

Foley, J. A. (2005). Global consequences of land use. *Science, 309*, 570-574. http://dx.doi.org/10.1126/science.1111772

Garbeva, P, van Veen, J. A., & van Elsas, J. D. (2004). Microbial diversity in soil: selection of microbial populations by plant and soil type and implications for disease suppressiveness. *Annual Review of*

Phytopathology, 42, 243-270. http://dx.doi.org/10.1146/annurev.phyto.42.012604.135455

Godoy, P., Nunes, F., Silva, V., Tomimori-Yamashita, J., Zaror, L., & Fischman, O. (2004). Onychomycosis caused by *Fusarium solani* and *Fusarium oxysporum* in Sao Paulo, Brazil. *Mycopathologia, 157*, 287-290. http://dx.doi.org/10.1023/B:MYCO.0000024186.32367.d4

Gorman, S. R., Magiorakos, A., Zimmerman, S. K., & Craven, D. E. (2006). *Fusarium oxysporum* pneumonia in an immune competent host. *Southern Medical Journal, 99*, 613-616. http://dx.doi.org/10.1097/01.smj.0000217160.63313.63

Goldblum, D., Frueh, B. E., Zimmerli, S., & Bohnke, M. (2000). Treatment of post Keratitis *Fusarium* endophthalmitis with amphotericin B lipid complex. *Cornea, 19*, 853-856. http://dx.doi.org/10.1097/00003226-200011000-00019

Inam-Ul-Haq, M., Javed, N., Ahsan-khan, M., Jaskani, M. J., Khan, M. M., Khan, H. U., … Gowen, S. R. (2009). Role of temperature, moisture and *Trichoderma* species on the survival of *Fusarium oxysporum ciceri* in the rainfed areas of Pakistan. *Pakistani Journal of Botany, 41*, 1965-1974.

Jarvis, W. R., & Shoemaker, R. A. (1978). Taxonomic status of *Fusarium oxysporum* causing foot and root rot of tomato. *Phytopathology, 68*, 1679-1680. http://dx.doi.org/10.1094/Phyto-68-1679

Jeschke, N., Nelson, P. E., & Marasas, W. F. O. (1990). *Fusarium* spp. isolated from soil samples collected at different altitudes in the Transkei, southern Africa. *Mycologia, 82*, 727-733. http://dx.doi.org/10.2307/3760159

Kedera, C. J., Plattner, R. D., & Desjardins, A. E. (1999). Incidence of *Fusarium* spp. and levels of Fumonisin B in Maize in Western Kenya. *Applied and Environmental Microbiology, 65*, 41-44.

Larkin, R. P., & Fravel, D. R. (2002). Effects of varying environmental conditions on biological control of *Fusarium* wilt of tomato by nonpathogenic *Fusarium* spp. *Phytopathology, 92*, 1160-1166. http://dx.doi.org/10.1094/PHYTO.2002.92.11.1160

Latiffah, Z., Mohd, Z. M., & Baharuddin, S. (2007). Diversity of *Fusarium* species in cultivated soils in Penang. *Malaysian Journal of Microbiology, 3*, 27-30.

Leslie, J. F., Pearson, C. A. S., Nelson, P. E., & Toussoun, T. A. (1990). Fusarium species from corn, sorghum, and soybean fields in the central and eastern United States. *Phytopathology, 80*(4), 343-350. http://dx.doi.org/10.1094/Phyto-80-343

Leslie, J. F., Summerell, B. A., & Bullock, S. (2006). *The Fusarium laboratory manual* (p. 388). New York: Wiley-Blackwell. http://dx.doi.org/10.1002/9780470278376

Louis, I., & Cooke, R. C. (1983). Influence of the conidial matrix of *Sphaerellopsis filum* (Darluca filum) on spore germination. *Trans BR Mycol Soc, 81*, 667-670. http://dx.doi.org/10.1016/S0007-1536(83)80151-X

Luque, A. G., Pioli, R., Bonel, B., & Alvarez, D. P. (2005). Cellulolytic fungi populations in stubble and soil as affected by agricultural management practices. *Bulletin of Agriculture Horticulture, 23*, 121-142. http://dx.doi.org/10.1080/01448765.2005.9755316

Maina, P. K., Okoth, S., & Monda, E. (2009). Impact of land use on distribution an diversity of *Fusarium species* in TaitaTaveta, Kenya. *Tropical and Subtropical Agroecosystem, 11*, 323-335.

Marasas, W. F. O., Burgess, L. W., Anelich, R. Y., Lamprecht, S. C., & Van Schalkwyk, D. J. (1988). Survey of *Fusarium* species associated with plant debris in South African soils. *S Afr J Bot, 54*, 63-71.

Mauseth, J. (2008). *Botany: An Introduction to Plant Biology* (p. 672). New York: Jones and Bartlett Publishers.

McGuire, K. L., Fierer, N., Bateman, C., Treseder, K. K., & Turner, B. L. (2012). Fungal community composition in Neotropical rain forests; influence of tree diversity and precipitation. *Microbial Ecology, 63*, 804-12. http://dx.doi.org/10.1007/s00248-011-9973-x

Mselle, J. (1999). Fungal keratitis as an indicator of HIV infection in Africa. *Tropical Doctor, 29*, 133-135.

Nelson, P. E., Toussoun, T. A., & Marassas, W. F. O. (1983). *Fusarium spp: An illustrated Guide for Identification* (p. 193). The Pennsylvania State University Press, University Park, PA.

Nemec, S. (1987). *Fusarium solani* association with branch and trunk cankers on citrus weakened by cold weather in Florida, USA. *Mycopathologia, 97*, 1443-150. http://dx.doi.org/10.1007/BF00437237

Nesci, A., Barros, G., Castillo, C., & Etcheverry, M. (2006). Soil fungal population in pre-harvest maize

ecosystem in different tillage practices in Argentina. *Soil Till Res, 91*, 143-149. http://dx.doi.org/10.1016/j.still.2005.11.014

Nurhazrati, M., Hafizi, R., Nor, A. I., Baharuddin, S., & Latiffah, Z. (2012). Diversity of *Fusarium* Species from Highland Areas in Malaysia. *Tropical Life Sciences Research, 23*(2), 1-15.

Nwanma, B. N. O., & Nelson, P. E. (1993). The distribution of *Fusarium* species in soils planted to millet and sorghum in Lesotho, Nigeria and Zimbabwe. *Mycopathologia, 121*, 105-114. http://dx.doi.org/10.1007/BF01103578

Okoth, P., Okoth, S., & Jefwa, J. M. (2013). The conservation and use of micro-organisms and invertebrates in root crop-based systems: State of knowledge, trends and future prospects. *Background study paper* (No. 63, p. 64). Commission on Genetic Resources for Food and Agriculture.

Rheeder, J. P., & Marasas, W. F. O. (1998). *Fusarium* species from plant debris associate with soils from maize producing areas in the Transkei region of South Africa. *Mycopathologia, 143*(2), 113-119. http://dx.doi.org/10.1023/A:1006975825586

Rousk, J., Brookes, P. C., & Baath, E. (2010). The microbial PLFA composition as affected by pH in an arable soil. *Soil Biology and Biochemistry, 42*, 516-520. http://dx.doi.org/10.1016/j.soilbio.2009.11.026

Salas, B., & Stack, R. W. (1991). Influence of tillage on soil populations of *Fusarium* species in a spring wheat cropping system. *Phytopathology, 81*(10), 1215-1216.

Senthilkumar, G., Madhanraj, P., & Panneerselvam, A. (2011). Studies on saprophytic survival of *Fusarium oxysporum* using precolonized paddy straw bits. *Journal of National Product and Plant Resources, 3*, 15-19.

Silvestro, L. B., Stenglein, S. A., Forjan, H., Dinolfo, M. I., Arambarri, A. M., Manso, L., & Moreno, M. V. (2013). Occurrence and distribution of soil *Fusarium* species under wheat crop in zero tillage. *Spanish Journal of Agricultural Research, 11*(1), 72-79. http://dx.doi.org/10.5424/2013111-3081

Siti, N. M. S., Nur, A. I. M. Z., Nur, A. A., & Salleh, B. (2012). Diversity of *Fusarium* species Isolated from Soil Cultivated with Cucurbits within East Coast, Peninsular Malaysia. *Pertanika J. Trop. Agric. Sci., 35*(2), 381-386.

Steinkellner, S., & Langer, I. (2005). Impact of tillage on the incidence of *Fusarium* spp. in soil. *Plant and Soil, 267*(1-2), 13-22. http://dx.doi.org/10.1007/s11104-005-2574-z

Summerell, B. A., Laurence, M. H., Liew, E. C. Y., & Leslie, J. F. (2010). Biogeography and phylogeography of *Fusarium*: A review. *Fungal Diversity, 44*(1), 3-13. http://dx.doi.org/10.1007/s13225-010-0060-2

Summerell, B. A., & Rugg, C. A. (1992). Vascular wilt of *Helichrysum* species caused by *Fusarium oxysporum*. *Australasian Plant Pathology, 21*, 18-19. http://dx.doi.org/10.1071/APP9920018

Thorn, R. G. (1997): The fungi in soil. In J. D. Van Elsas, J. T. Trevors & E. M. H. Wellington (Eds.), *Modern soil microbiology* (pp. 63-108). Marcel Dekker, NY.

Vakalounakis, D. J., & Chalkias, J. (2004). Survival of *Fusarium oxysporum* f. sp. *radicis-cucumerinum* in soil. *Crop protection, 23*, 871-873. http://dx.doi.org/10.1016/j.cropro.2004.01.011

Wakelin, S. A., Warren, R. A., Kongand, L., & Harvey, P. R. (2008). Management factors affecting size and structure of soil *Fusarium* communities under irrigated maize in Australia. *Applied Soil Ecology, 39*, 201-209. http://dx.doi.org/10.1016/j.apsoil.2007.12.009

Wei, W., Xu, Y. L., Li, S., Liu, J. B., Han, X. Z., Li, W. B., & Ji, P. (2012). Analysis of *Fusarium* populations in a soybean field under different fertilization management by real-time quantitative PCR and Denaturing Gradient Gel Electrophoresis. *Journal of Plant Pathology, 94*(1), 119-126.