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EFFECT OF INTEGRATED SOIL FERTILITY MANAGEMENT INTERVENTIONS ON THE ABUNDANCE AND DIVERSITY OF SOIL COLLEMBOLA IN EMBU AND TAITA DISTRICTS, KENYA

[EFECTO DEL MANEJO INTEGRADO DE LA FERTILIDAD DEL SUELO SOBRE LA ABUNDANCIA Y DIVERSIDAD DE COLLEMBOLA EN SUELOS DE LOS DISTRITOS DE EMBU Y TAITA, KENIA]

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SUMMARY

The study aimed at identifying soil fertility management practices that promote the Collembola population, diversity and survival in the soil. Soil samples were randomly collected from on farm plots amended with: 1-Mavuno ((Ma)-is a compound fertilizer containing 26% Potassium, 10% Nitrogen, 10% Calcium, 4% Sulphur, 4% Magnesium and trace elements like Zinc, Copper, Boron, Molybdenum and Manganese)), 2-Manure (Mn), 3-*Trichoderna* (Tr) inoculant (is a soil and compost-borne antagonistic fungus used as biological control agent against plant fungal diseases), 4-Farmers practice ((FP) where Tripple Super Phosphate (T.S.P.) and Calcium Ammonium Nitrate (C.A.N.) fertilizers are applied in the soil in mixed form), 5-Tripple Super Phosphate (T.S.P.), 6-Calcium Ammonium Nitrate (C.A.N.). These treatments were compared with 7-Control (Co) (where soil fertility management interventions where not applied). Soil Collembola were extracted using dynamic behavioural modified Berlese funnel and identified to the genus level. Occurrence of Collembola was significantly affected by soil fertility amendments in both Taita and Embu study sites ($P<0.05$). Twenty two genera of soil dwelling Collembola were recorded, with control and organic manure treated plots recording high diversity with a Shannon 1.86 in Embu and a Shannon 2.09 in Taita, respectively. There was significant difference ($P<0.05$) of seasonality on soil Collembola occurrence at both Embu and Taita. Application of cow manure and addition of *Trichoderma* inoculants promoted the soil Collembola. The study has demonstrated that application of organic amendments encouraged the soil Collembola while inorganic fertilizers negatively impacted on these soil organisms.

Key words: Soil Collembola; *Trichoderma;* Organic manure and inorganic fertilizers

INTRODUCTION

Low soil fertility is a major constraint affecting agricultural production in sub-Saharan Africa, leading to decline in per capita food production (Mokwunye *et al*., 1996; Sanchez *et al*., 1997). Soil fertility degradation is "alteration to all aspects of the natural (or biophysical) environment by human actions leading to detrimental effects on vegetation, soils, landform, water and ecosystems'' (Swift and Shepherd, 2007). Loss of vegetation leads to soil degradation and in turn reduces biodiversity. Soil is a habitat representing a complex mixture of inorganic and organic fractions, with water and living organisms. An array of the living organisms in three taxonomic domains is common in the soil (Woese *et al*., 1990). These are grouped into three broad diverse assemblage of the belowground biodiversity namely Bacteria, Arcaea and Eucaryota. The soil fauna, a part of Eucaryota is grouped into macrofauna, mesofauna and microfauna (Giller *et al*., 1997). These soil biota contribute positively to ecosystem processes (Swift and Bignell, 2000, Wall, 2004) which in turn support provision of ecosystems services that contribute to the maintenance and productivity of ecosystems by influencing soil quality and health (Brussaard *et al*., 1997; Kibblewhite *et al*., 2008). The soil quality and health influence fauna abundance and diversity. The belowground biodiversity has notable relevance to the health of crops, trees and plants desirable to man. Microorganisms like *Trichoderma* also play key roles in suppressing soil-borne plant diseases and promoting plant growth (Garbeva *et al.*, 2004). Soil fauna play an important role of transforming the quality of soil by regulating the structure and functioning of microbial communities, shredding and digesting organic matter (Ponge *et al*., 2003). Among the mesofauna organisms, the Collembola contribute immensely to the addition of soil nutrients through organic matter decomposition (Ponge *et al*., 2003).

Agricultural intensification involves high input application to replenish soil fertility, especially the use of inorganic fertilizers (Shriar, 2000; TSBF, 2003). Continued use of inorganic fertilizers has not only altered the pH soil, soil structure and texture but also disrupted the niches for micro-and mesofauna, which are essential for nutrient recycling (Ponge *et al*., 2003; Moreira *et al*., 2006). Presently, increased emphasis is on application of Integrated Pest Management (IPM). Farming practices such as IPM may affect abundance and diversity of the Collembola as they are very sensitive to alteration in crop management practices (Rebek *et al*., 2002). Studies conducted on the effect of land use intensification, soil chemistry and soil organic matter on the abundance and diversity of Collembola in France, Portugal and Brazil, have shown that, they have a significant effect on the population of Collembola communities (Ponge *et al*., 2003; Jose' *et al*., 2004; 2005; Syrek *et al*., 2006). The Collembola are sensitive to a wide range of micro-climatic changes and disturbances, inclusive of human activities hence are important bioindicators of the human induced changes in the soil systems (Lauga-Reyrel and Deconchat, 1999). There is limited information in Kenya on the influence of land use practices on belowground biodiversity (BGDB) especially the Collembola communities which play a key role in organic matter decomposition. The purpose of the current study was to evaluate the effect of application of organic and inorganic fertilizer and *Trichoderma* in the soil on the abundance and diversity of the Collembola communities.

MATERIALS AND METHODS

The study was conducted in two districts of Kenya, in Embu, Eastern Province and the Taita-Taveta in Coast Province, during the wet cropping and dry seasons of 2007 to 2009. The site in Embu was located at the Agricultural Training College (ATC) farm in Embu, at an altitude of 1480 m above sea level (Kiome and Muya, 1999). The soils are deep, well weathered with friable texture, with moderate to high fertility (Gachimbi, 2002). They are mainly Humic Nitisols (Jaetzold and Schmidt, 1983). The site in Taita-Taveta was located at the Taita Agricultural Training College (ATC) farm within Wundanyi division, at altitude 580 m above sea level. The soils are deep, well drained, dark brown varying from sandy clay loam to clay. In both sites the plots were established in an area which had been left fallow for two years. A block with seven plots, each measuring 3m by 3m with one meter footpath around the plots were established. All the plots were cultivated with a fork and properly leveled with a rake. Soil treatments/soil amendments were randomly allocated per plot except one plot which acted as control where no treatment was applied. This kind of set up was replicated five times hence five blocks each with seven plots. The soil treatment involved application of the following soil amendments; 1-Mavuno (Ma) P 50 kg per hectare, 2-Manure (Mn) 10 tons per hectare, 3-*Trichoderna* (Tr) seeds were coated with *Trichoderma* at rate of 2 grams of *Trichoderma* per one kilogram of seeds and gum Arabic used as a sticker, and 4-FP (Farmers practice where Triple Super Phosphate (T.S.P.) P 50 kg per hectare and Calcium Ammonium Nitrate (C.A.N.) N 100 kg per hectare was used), 5- Triple Super Phosphate (T.S.P.), 6-Calcium Ammonium Nitrate (C.A.N.) fertilizers was applied and 7-Control (Co)(plots where soil fertility management interventions where not applied). In the plots were *Trichoderma* was used, the seeds were inoculated through seed coating with *Trichoderma* at rate of 2 grams of *Trichoderma* per one kilogram of seeds and gum Arabic used as a sticker before planting. After broadcasting the inputs, they were mixed with the soil with a rake. All the plots including the control were then sown with maize (511 hybrid) at a spacing of 90cm x 30 cm, two seeds per hole and beans (Rose coco) two seeds per hole at spacing of 30 cm in alternate rows. The experiment was repeated for four consecutive seasons. In each plot, nine sub-samples of soil were collected to make composite of three samples. Collembola were sampled using a soil core of 5 cm wide and at depth of 5 cm. Collembola were extracted using dynamic behavioural modified Berlese funnel (Moriera *et al*., 2008) and were identified to the genus level (Hopkin, 2007).

Data analysis

Data collected was analyzed using analysis of variance (ANOVA). Prior to analysis, data were normalized using log transformation. Biodiversity descriptions estimated; genera abundance, richness StatSoft, 2003, Shannon diversity index (Kindt and Coe, 2005) and Renyi index. The mean values were compared using the Student Newmen Keulis Test (SNK) test (Zar, 1999) when ANOVAs were significant.

RESULTS

There were significant differences among soil fertility management treatments $p \leq 0.0001$ in terms of mean density of Collembola in Embu and Taita soils (Table 1 and 2). In Embu, there was significant difference in mean density between control and all the other treatments. Application of organic inputs (cow manure and *Trichoderma*) increased abundance of the soil Collembola while inorganic fertilisers impacted negatively $p \leq 0.0001$. In Embu the highest mean density of Collembola was found in the control plots where no soil amendments was done, followed by treatments with manure and other organic treatments and the lowest abundance in treatments with inorganic amendments. In Taita, there was significant difference in mean density between organic amendments and inorganic amendments with low density recorded in plots with inorganic amendments. But densities were generally twice as high in Taita as in Embu. Collembola sampled showed higher diversity in soils amended with organic manure to inorganic fertilisers.

Table 1. Effect of integrated soil fertility management on mean abundance and mean diversity of Collembola in Embu soils (mean of four cropping seasons).

Treatment	Mean density (m^{-2})	Mean richness (m^{-2})
Control	738.6±125.2a	2.8±0.3a
Manure	586.1±100.2ab	2.4±0.2ab
Manure + *Trichoderma*	345.4±85.2b	1.6±0.3ab
Trichoderma	325.6±65.2b	1.6±0.3ab
Mavuno	263.3±72.0b	1.2±0.2c
Mavuno + *Trichoderma*	243.5±84.7b	1.4±0.3c
T.S.P. + C. A. N.	240.7±65.7b	1.4±0.2c
F-value	4.895	5.375
P-value	0.0001	0.0001

Values followed in column by similar letters not significantly different at $p \leq 0.0001$

There was higher abundance of Collembola in year one than in second year. In both years during the four seasons both in Embu and in Taita, the highest mean density was recorded in the wet season and the lowest recorded in dry season. The same trend was evident with the mean richness, where diversity reduced with the increase in dry spell (Table 3 and 4).

Table 2. Effect of integrated soil fertility management on mean abundance and mean diversity of Collembola in Taita soils (mean of four cropping seasons).

Treatment	Mean density (m^{-2})	Mean richness (m^{-2})
Manure	1639.3±259.1b	3.6±0.4b
Control Manure +	1466.6±215.9b	3.8±0.4b
Trichoderma	1395.8±209.9b	3.4±0.4ab
Mavuno + *Trichoderma*	1152.3±177.9b	3.1±0.3ab
T.S.P. + C. A. N.	673.8±116.5a	2.4±0.2a
Mavuno	665.3±131.2a	2.2±0.2a
Trichoderma	617.2±96.2a	2.3±0.3a
F-value	5.681	4.5328
P-value	0.0001	0.0001

Values followed in column by same letters not significantly different at $p \leq 0.0001$

Table 3. Effect of seasonality on mean density (m^{-2}) and mean richness of soil Collembola in Embu fertility management experiment (mean of four seasons).

Season	Mean density (m^{-2})	Mean richness
1-Wet	656.9±84.7a	2.4±0.2a
2-Dry	561.4±74.2a	2.3±0.2a
3-Wet	257.2±43.8b	1.5±0.2b
4-Dry	92.2±17.9b	0.8±0.2c
F-value	18.478	16.758
P-value	0.0001	0.0001

Values followed in column by same letters not significantly different at $p \leq 0.0001$

Table 4. Effect of seasons on mean density and mean richness of soil Collembola in Taita fertility management experiment during the four cropping seasons of 2007 to 2009.

Season	Mean density (m^{-2})	Mean richness
1-Wet	967.5±88.3b	2.4±0.2a
2-Dry	1616.2±190.9c	3.4±0.3b
3-Wet	1250.6±152.3c	3.5±0.3b
4-Dry	514.5±74.7a	2.4±0.1a
F-value	11.851	6.684
P-value	0.0001	0.0001

A total of 969 individuals of soil dwelling Collembolan representing four families and nine genera were sampled from all the plots under different soil fertility management regimes in Embu. The genus *Isotomiella* was the most frequently sampled with cumulative frequency of 26.8%. Other genera were: *Cryptopygus, Folsomina, Parisotoma, Lepidocyrtus, Ceratophysella, Folsomides, Tullbergia* and *Hypogastrura* (Table 5). Most of the soil dwelling Collembola were sampled in control plots. Among the soil amendments, plots with cow manure and *Trichoderma* had the highest densities while lower densities were found in soils were only inorganic fertilisers were applied (Table 6). High and diverse soil Collembolan population were sampled in rainy season but, the trend is reversed in subsequent seasons. Organic amendments favoured species richness Shannon 1.861 (Table 7).

Table 5. Frequency of occurrence of soil dwelling Collembola under different soil fertility management in four seasons of 2007 to 2009 in Embu, Kenya.

Genera	No. of Collembola sampled	Frequency (%)
Isotomiella	260	26.8
Cryptopygus	248	25.6
Folsomina	174	18.0
Parisotoma	76	7.8
Lepidocyrtus	74	7.6
Ceratophysella	50	5.2
Folsomides	47	4.9
Tullbergia	30	3.1
Hypogasrura	10	1.0
Total	969	100.0

Table 6: Total number of Collembola individuals sampled in different soil fertility managements, genera richness and diversity index in Embu during the four cropping seasons of 2007 to 2009.

Treatment	Abundance	Richness	Shannon index
Control	261	9	1.773
Manure	207	8	1.708
Manure and *Trichoderma*	122	9	1.731
Mavuno	93	6	1.330
Mavuno and *Trichoderma*	86	7	1.804
Trichoderma	115	8	1.732
T.S.P. and C.A.N.	85	6	1.628

In Taita a total of 2688 soil dwelling Collembola represented in seven families and thirteen genera were sampled from all the plots under different integrated soil fertility management regimes. The genus *Parisotoma* was the most frequently sampled with cumulative frequency of 24.0%. Other genera were: *Folsomia, Tullbergia, Oncopodura, Folsomides, Lepidocyrtus, Cryptopygus, Ceratophysella, Entomobrya, Isotoma, Thalassaphorura* and *Sminthurus* (Table 8). High numbers of soil dwelling Collembola were sampled in control plots followed by plots with cow manure. A decrease in soil Collembola population was observed in soils were inorganic fertilisers like T.S.P. and C.A.N. were applied (Table 9). High soil Collembola population densities were sampled in season 1 and 2 but, numbers reduced progressively with higher diversity being realised in season 3 and 4. Cow manure and *Trichoderma* favoured species richness, Shannon 2.093 (Table 10).

Table 7: Total number of Collembola individuals sampled in different seasons, genera richness and diversity index in Embu (mean of four seasons).

Season	Genera abundance	Genera richness	Shannon index
1 (Wet season 2007)	406	9	1.811
2 (Dry season 2008)	347	9	1.764
3 (Wet season 2009)	159	8	1.879
4 (Dry season 2009)	59	6	1.328

Table 8: Frequency of occurrence of soil dwelling Collembola under different treatment regimes in four seasons of 2007 to 2009 in Taita, Kenya.

Genera	No. of Collembola	Frequency
Parisotoma	644	24.0
Hypogastrura	459	17.1
Folsomia	458	17.0
Tullbergia	374	13.9
Oncopodura	205	7.6
Folsomides	148	5.5
Lepidocyrtus	137	5.1
Cryptopygus	128	4.8
Ceratophysella	58	2.2
Entomobrya	28	1.0
Isotoma	23	0.9
Thalassaphorura	21	0.8
Sminthurus	5	0.2
Total	2688	100

Table 9: Total number of Collembola individuals sampled in different soil fertility managements, genera richness and diversity index in Taita soils (in four cropping seasons).

Treatment	Abundance	Genera richness	Shannon index
Control	518	11	1.980
Manure	579	11	2.162
Manure and *Trichoderma*	493	12	2.139
Mavuno	235	9	1.785
Mavuno and *Trichoderma*	407	10	1.962
Trichoderma	218	9	1.814
T.S.P. and C.A.N.	238	9	1.768

Table 10. Total number of Collembola individuals sampled in different seasons, genera richness and diversity index in Taita during the four cropping seasons.

Season	Abundance	Genera richness	Shannon index
1 (Wet season 2007)	598	9	1.967
2 (Dry season 2008)	999	10	1.845
3 (Wet season 2009)	773	11	2.090
4 (Dry season 2009)	318	10	2.109

The diversity profiles both in Embu and Taita of soil dwelling Collembola in the four seasons showed that wet season exhibited a higher diversity of Collembola than in the dry season. Plots with organic amendments and those which had no applications of any soil amendment supported a more diverse soil Collembola community than those where the inorganic fertilisers were used. The evenness profiles showed that wet season was most even with dry season being the least even. The treatment evenness profiles show that the plots where soil had been treated with cow manure and *Trichoderma* were more even while, the plots treated with inorganic fertilisers were less even.

DISCUSSION

Application of cow manure and *Trichoderma* in the soil during the growth period of the crop supported high abundance and diversity of Collembola as evidenced by the high numbers sampled in plots treated with the same. Several Collembola genera were sampled during the study. The genera include *Isotomiella, Cryptopygus, Folsomina, Parisotoma, Lepidocyrtus, Folsomina, Oncopodura, Entomobrya, Isotoma, Thalassaphorura and Sminthurus.* The varied genera occurrence may have been influenced by organic amendments which provided organic matter. The organic matter improves soil conditions, soil pH, and structure, water holding capacity and directly provide food resource for the eudaphic Collembola and indirectly crop growth like root residues. The findings agree with studies by (Lagerlöf and Andrén, 1991, Mäder *et al*., 1997 and Wardle *et al*., 1999a) who found that arthropod taxa are generally high at high organic matter input or in organic farming systems. Wachira, (2009) while evaluating the effect of organic amendments on nematode-destroying fungi and plant parasitic nematodes found that the use of chicken manure stimulated build-up of the nematode destroying fungi. We recorded few soil Collembola in plots that were treated with inorganic fertilisers (Mavuno, T.S.P. and C.A.N) over the four seasons. Probably, this may have been due to reduction in organic food resource and changes in soil conditions like soil pH, water holding capacity, bulk density and soil temperature. Similarly, inorganic fertilisers cause increased crop growth hence more water usage by the plant making the soil to have low moisture content essential for the Collembola. Filser *et al*., (1999) found that soil management practices contributed to the variation of microbial biomass. From this study, cow manure, application of *Trichoderma* on seeds before planting and the combination of cow manure and *Trichoderma* as well as lack of application of amendments over the time favoured Collembola population build up and diversity. Application of *Trichoderma* may have increased fungal flora and positively provided substrate for Collembola. Wachira, (2009) and Okoth, *et al*., (2009) have reported enhanced population build up of fungi like *arthrobotrys* species in organic amendment plots. High organic matter, shade, high soil carbon and nitrogen have a significant influence in supporting high population of soil Collembola and Mites (Muturi *et al*., 2009 and Maribie, 2009). The presence of organic manure resulted in an increase in the abundance and diversity of total collembolan. The genera *Parisotoma* and *Isotomiella* in the family Isotomidae were predominant which indicated that they benefited from the organic litter coming from manure which may have increased microbial biomass in the rhizosphere of roots. Rosilda *et al*., (2002) found that populations of soil Acari and Collembola increased with increase in organic matter content of the soil. The low numbers in presence of inorganic fertilisers implied that they negatively impacted on populations of Collembola.

In this study high numbers of soil Collembola were sampled in the wet seasons in Embu and Taita. It implies that, soil Collembola population were dependant on soil moisture and to some extent the soil temperatures. The weather variation witnessed during the study characterised by the high temperatures may have led to either vertical migration of soil Collembola to the lower soil levels, aestivation, eggs remaining dormant or lower reproductive rate hence, the low counts recorded in the last dry season. Members of the family Isotomidae were most predominant in almost all plots may be due to their high reproductive rate and adaptive ability. The varied species abundance and diversity in the different seasons and in varied integrated soil fertility management practices is consistent with the findings by lauga-Reyrel and Deconchat, (1999) and Rosilda *et al*., (2002), who reported that the group respond to changes in land use and soil conditions.

In conclusion the study has demonstrated the potential of organic soil amendments in enhancing edaphic soil Collembola as well as diversity due to the increased substrate niche for soil Collembola. However, dry conditions negatively affect the trend. Therefore, use of organic manure in agricultural fields would not only boost agricultural food production, but, also sustain soil Collembola which are important in nutrient cycling.

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