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ABUNDANCE AND DIVERSITY OF SOIL MITES (ACARI) ALONG A GRADIENT OF LAND USE TYPES IN TAITA TAVETA, KENYA

[ABUNDANCIA Y DIVERSIDAD DE ACAROS DEL SUELO EN UN GRADIENTE DE TIPO DE USO DEL SUELO EN TAITA TAVETA, KENIA]

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SUMMARY

The abundance and diversity of soil mites was monitored along a gradient of land use types (LUTs) during the wet seasons in soils of Taita Taveta, Kenya. Sampling of mites from soils was carried out in eight LUTs which included maize-based system (*Zea mays)*, coffee (*Coffea Arabica)*, horticulture, napier grass (*Pennisetum purpureum*), fallow, pine (*Pinus patula)*, cypress (*Cypressus lusitanica)*, natural forest.

LUT significantly influenced abundance, richness and diversity of the soil mites. During the short rains the diversity of soil mites increased in the order napier ,maize-based system, horticulture, coffee, fallow, natural forest, pine forest, cypress plantation while the long rains season abundance increased in the order maize-based system, coffee, horticulture, napier, natural forest, fallow, pine forest, cypress forest. Higher abundance, richness and diversity of the mites was observed in the less disturbed forest ecosystems unlike the agro-ecosystems, which are often disturbed with intensive cultivation A total of 37 families were recorded with 20 oribatid families, 10 mesostigmatid families and 7 prostigmatid families. The families that ranked highest in abundance across the LUT were Scheloribatidae, Oppidae (Oribatida) and Rhodacaridae (Mesostigmata).

Land use type influenced significantly (P<0.05) the abundance and diversity of soil mites where intensification lowered the diversity and abundances resulting in less complex mites community structures.

Key words: Land use type; soil mites; abundance; Diversity; agro-ecosystem; forest ecosystem.

INTRODUCTION

The alterations of natural habitats to agricultural land, plantations and pastures are among the main human activities that threaten ecosystem stability and biodiversity (Barrios, 2007; Rantalainen, 2006; Harriah *et al*., 2001; Schatzt, 1998). Agricultural practices alter not only the abundance and dynamics of different organisms and nutrients in the soil, but also affect the structure and dynamics of the food webs (Moore, 1994). The soil microflora and fauna complement each other in communition of litter, mineralization of essential plant nutrients and conservation of these nutrients within the soil system (Marshall, 2000). Free living soil mites are abundant soil organisms that are sensitive to soil perturbations in agricultural practices and their number and diversity often get reduced affecting their ecosystem services (Minor and Cianciolo, 2007). Several genera of soil mites are considered good bio-indicators of habitat and soil conditions (Behan-Pelletier, 1999). E.g., Minor and Cianciolo, (2007) found that the overall structure of Oribatida and Mesostigmata assemblages are significantly related to LUTs in both agricultural and natural land, where diversity of orbitidid mites was found to be highest in forest, followed by abandoned fields, willow and least in corn fields.

Due to anthropogenic activities the world faces potential major environmental and climatic changes. Climatic changes will affect seasons, which have been demonstrated to affect the soil mites' abundance and diversity (Badejo *et al*., 2002; Badejo and Tian 1999; Badejo 1990). It is hence necessary to understand how the ecosystems function in their natural states if there is any hope of returning ecosystems that have been deteriorated by human activities to beneficial modes and hence basic research in soil organism function is necessary (Elliot *et al.*, 1988).

In this study we hypothesized that abundance and diversity of soil mites increase from intensively managed agroecosystem to less disturbed forest ecosystem. The objective of the study was to determine the effect of LUTs and seasons on abundance and diversity of soil mites.

METHODS

Description of the study site

The site is located in the Taita hills area in Taita Taveta district which is 327 km South East of Nairobi and 159km North-west of Mombasa. It is approximately located at latitude 03^o 15'-03^o 30' S and longitude 38^o 15'-38^o 30' E and an altitude of approximately 580m above sea level (Bytebier, 2001). It borders Tsavo National park to the north and east, Sagala Hills to the south, and Voi sisal estates to the west (Pellika *et al*., 2004). The area receives mean annual rainfall of 1100mm with a bimodal pattern. The mean maximum temperature is 22.6^{o}C and mean minimum temperatures being 18.5^{o}C (Pellikka *et al*., 2004).

The main soils in Taita Taveta site are Haplic Acrisoils, Eutric Cambisols, Chromic Luvisols and Regosols. The soils of Taita Taveta are well drained to excessively drained, dark reddish brown to dark brown shallow to extremely deep, friable to firm and compact, sandy clay loam to clay (Kariuki and Muya, 2005).

Soil sampling for extraction of mites

Sampling was done along a transect from the Ngangao forest in Taita hills through a gradient of different LUTs. Sixty sampling points 200m apart were mapped and they fell on maize-based system (*Zea mays)*, coffee (*Coffea Arabica)*, horticulture, napier grass (*Pennisetum purpureum*), fallow, pine (*Pinus patula)*, cypress (*Cypressus lusitanica)*, and natural forest. There were four replicates of each LUT with exception of napier grass with three. Sampling was carried in two wet seasons; during short rains in October-November 2007 and the long rains in April 2008. Using a steel soil corer with a diameter and depth of 05 cm. 12 sub-samples of soil together with litter were collected to a depth of 05 cm at each sampling point and composed into three samples (Fig. 1). The samples were placed in polythene bags and transported to the laboratory for mites extraction using modified Berlese-Tullgren funnel (Krantz, 1978) and sorted out from the rest of soil organisms collected under dissecting microscope. The isolates were preserved in 75% ethanol with 2% glycerine waiting for sorting out. After sorting out and counting, mites were preserved permanently in Oudeman's fluid (Krantz, 1978) for enumeration and identification which was done to family level using published keys described by Norton, (1990), Krantz and Ainscough, (1990), Balogh and Balogh, (1992). The reference specimens at Acarology laboratory, Museum of biological diversity at Ohio State University, U.S.A were also used in identification.

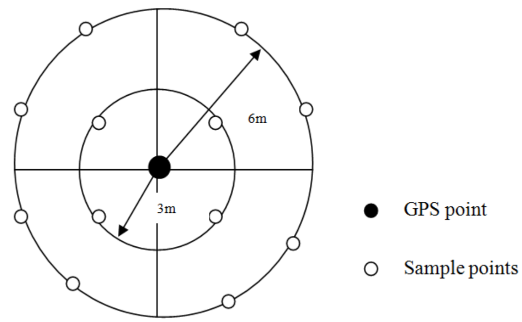


Figure 1. A layout of the mites sampling design

Data analysis

Analysis was done on untransformed data as it conformed to the assumptions of the model. Abundance of mites was expressed as the number of individuals per LUT. Family richness was expressed as the number of families represented per LUT while Shannon-Weiner diversity index was calculated to represent the diversity of soil mites per LUT (Kindt and Coe, 2005). Data was subject to ANOVA while Turkey's pair-wise comparison (Fisher test) was applied to separate effects of LUTs. Principal component analysis (PCA) was used to examine and display through ordination plots, the relationship of mite families matrix with LUTs. The cumulative number of families observed was plotted as family accumulation curve for the sites sampled. Jack knife estimate was used to represent estimated richness of the sampled sites. All statistical tests were conducted at the level of significance of $P \leq 0.05$ using R software, version 2.1.1 (R development core team, 2005).

RESULTS

Abundance, Richness and Diversity of the soil mites in different LUTs in Taita Taveta

The mean diversity of soil mites at Taita in the short rain season differed significantly (P<.001) among the LUTs (Table 1). Cypress plantation, pine and natural forest had significantly higher mites diversity compared to napier, horticulture, maize based and coffee (Table 1).

The mean abundance, richness and diversity from the different LUTs were significantly different (P<0.05) with soils collected from the pine and cypress plantations recording highest (Table 2). The agro-ecosystems had the lowest mean richness while fallow and the forest ecosystems had the highest mean richness in ascending order horticulture, maize-based, napier, natural forest, pine plantation, cypress plantation (Table 2). Pine and cypress plantation forests and the natural forest had significantly (*P*<0.05) higher diversity than napier, fallow, horticulture and maize-based (Table 2).

During the short rains, 37 families were recovered with the Jackknife estimate projecting 41.84±2.01 families indicating adequate sampling as no more families would be found with additional sampling effort (Figure 2, Table 3). In the long rains season, 36 families were recovered with the Jackknife population estimate projecting 42.77±3.32 families (Figure 2, Table 4).

Table 1. Mean abundance, richness and diversity of soil mites at Taita Taveta during the short rains in Oct-Nov. 2007

LUT	Abundance	Family richness	Shannon-Weiner Diversity index
Natural forest	62.3±18.1b	11.5±1.9ab	2.13±0.1a
Maize-based	76.5±22.9b	7.0±0.9b	1.26±0.1bc
Pine forest	90.3± 23.8b	12.3±1.0ab	2.13±0.1a
Coffee	134.3±33.2b	11.3±1.6ab	1.68±0.1b
Horticulture	164.8±62.7b	9.0±1.9b	1.30±0.3bc
Fallow	204.0±90.2ab	10.5±2.9ab	1.64±0.2b
Napier	259.0±173.0ab	7.3±2.3b	0.99±0.1c
Cypress forest	413.8± 159.0a	15.5±1.7a	2.20±0.1a
	$F_{7,23}$=1.89	$F_{7,23}$=2.22	$F_{7,23}$=8.61
	P=0.118	P=0.071	P<.001

Means with the same letter(s) in the same column are not significantly different at $P≤0.05$ (Fisher test)

Table 2. Mean abundance, richness, and diversity of soil mites at Taita Taveta during the long rain season in April 2008.

LUT	Mean abundance	Mean richness	Shannon-Weiner Diversity index
Maize-based	72.3±24.7d	6.5±1.9c	1.3±0.3bc
Coffee	120.5±25.7d	10.8±1.1bc	1.8±0.1ab
Horticulture	132.3±22.7d	6.0±1.1c	1.1±0.3c
Napier	147.7±70.1cd	8.7±2.3bc	1.1±0.3c
Natural forest	244.0±63.3bcd	12.3±0.9ab	2.1±0.1a
Fallow	413.8±79.4abc	12.0±2.9ab	1.1±0.2c
Pine forest	436.2±181.7a	15.8±1.6a	2.0±0.2a
Cypress forest	607.0±118.8a	16.8±1.1a	2.2±0.2a
	$F_{7,23}$=4.51	$F_{7,23}$= 5.50	$F_{7,23}$= 5.57
	P=0.003	P<.001	P<.001

Means with the same letter(s) in the same column are not significantly different at $P≤0.05$ (Fisher test)

Appendix 2 (a): Total abundance and relative abundance of soil mites in Oct-Nov. season (2007) at Taita.

	CO		**C. F.**		**F**		**H**		**M-B**		**NA**		**N. F.**	
Mite group	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%
Oribatida														
Scheloribatidae	158	2.95	229	4.27	254	4.74	228	4.25	58	1.08	400	7.46	23	0.4
Peloppiidae	0	0.00	4	0.07	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Otocepheidae	1	0.02	10	0.19	0	0.00	0	0.00	0	0.00	0	0.00	2	0.0
Northridae	3	0.06	36	0.67	0	0.00	8	0.15	0	0.00	0	0.00	0	0.0
Neolididae	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Galumnidae	109	2.03	42	0.78	31	0.58	34	0.63	17	0.32	3	0.06	20	0.3
Oppiidae	21	0.39	122	2.28	32	0.60	42	0.78	6	0.11	6	0.11	41	0.7
Pthiracaridae	1	0.02	3	0.06	11	0.21	1	0.02	1	0.02	0	0.00	1	0.0
Eupthiracaridae	0	0.00	2	0.04	19	0.35	0	0.00	1	0.02	0	0.00	0	0.0
Damaeidae	3	0.06	2	0.04	2	0.04	3	0.06	1	0.02	0	0.00	4	0.0
Haplozetidae	8	0.15	63	1.18	28	0.52	27	0.50	0	0.00	3	0.06	6	0.1
Carabodidae	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
nr. Metrioppiidae	10	0.19	0	0.00	4	0.07	1	0.02	0	0.00	0	0.00	0	0.0
Liacaridae	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
Hermanniidae	0	0.00	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	1	0.0
Mesoprophoridae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
Lohmanniidae	2	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Gymnodamaeidae	0	0.00	21	0.39	0	0.00	4	0.07	0	0.00	0	0.00	1	0.0
Eulohmanniidae	4	0.07	0	0.00	5	0.09	0	0.00	0	0.00	0	0.00	1	0.0
Juveniles	72	1.34	299	5.58	149	2.78	138	2.57	55	1.03	161	3.00	53	0.9
Mesostigmata														
Rhodacaridae	24	0.45	164	3.06	90	1.68	45	0.84	58	1.08	43	0.80	17	0.3
Laelapidae	7	0.13	30	0.56	40	0.75	5	0.09	6	0.11	19	0.35	13	0.2
Ologamasidae	24	0.45	158	2.95	4	0.07	3	0.06	2	0.04	1	0.02	9	0.1
Macrochellidae	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00	4	0.07	0	0.0
Parasitidae	0	0.00	0	0.00	0	0.00	5	0.09	0	0.00	0	0.00	0	0.0
Uropodidae	28	0.52	14	0.26	28	0.52	21	0.39	4	0.07	28	0.52	14	0.2
Pachylaelapidae	0	0.00	8	0.15	13	0.24	0	0.00	0	0.00	9	0.17	0	0.0
Polyaspididae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Digamasellidae	0	0.00	6	0.11	7	0.13	0	0.00	0	0.00	0	0.00	0	0.0
Sejidae	0	0.00	2	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Juveniles	47	0.88	221	4.12	87	1.62	82	1.53	89	1.66	86	1.60	26	0.4
Prostigmata														
Cunaxidae	5	0.09	17	0.32	4	0.07	7	0.13	4	0.07	10	0.19	2	0.0
Trombiididae	1	0.02	0	0.00	1	0.02	0	0.00	1	0.02	1	0.02	1	0.0
Chelytidae	0	0.00	0	0.00	1	0.02	0	0.00	2	0.04	2	0.04	0	0.0

Eupodidae	0	0.00	44	0.82	2	0.04	1	0.02	0	0.00	0	0.00	6	0.1
Rhagididae	0	0.00	69	1.29	3	0.06	0	0.00	0	0.00	0	0.00	5	0.0
Bdellidae	1	0.02	2	0.04	0	0.00	0	0.00	1	0.02	1	0.02	0	0.0
Tetrachnoidea	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00	0	0.00	0	0.0
Juveniles	0	0.00	84	1.57	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Astigmata (Hypopus)	7	0.13	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Total mites	537	10.02	1655	30.88	816	15.22	659	12.29	306	5.71	777	14.50	249	4.6
Total mite groups	20		25		21		18		14		14		21	

Key: CO-coffee, C.F-Cypress forest, F-Fallow, H-Horticulture, M-B-Maize-Based, NA-Napier, N.F- Natural forest, P.F-Pine

Appendix 2 (b): Total abundance and relative abundance of soil mites in the Long rain season in April 2008 (2008) at Ta

	CO		**C. F.**		**F**		**H**		**M-B**		**NA**		**N. F.**	
Mite group	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%
Oribatida														
Scheloribatidae	58	0.68	115	1.35	184	2.15	234	2.74	72	0.84	55	0.64	100	1.17
Peloppiidae	0	0.00	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Otocepheidae	1	0.01	12	0.14	0	0.00	0	0.00	0	0.00	0	0.00	5	0.06
Northridae	11	0.13	89	1.04	2	0.02	2	0.02	5	0.06	0	0.00	0	0.00
Neolididae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Galumnidae	36	0.42	74	0.87	13	0.15	0	0.00	13	0.15	3	0.04	24	0.28
Oppiidae	10	0.12	263	3.08	16	0.19	21	0.25	3	0.04	19	0.22	87	1.02
Pthiracaridae	0	0.00	9	0.11	5	0.06	0	0.00	0	0.00	1	0.01	0	0.00
Eupthiracaridae	0	0.00	8	0.09	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00
Damaeidae	9	0.11	25	0.29	15	0.18	0	0.00	10	0.12	0	0.00	4	0.05
Haplozetidae	12	0.14	81	0.95	16	0.19	2	0.02	0	0.00	2	0.02	10	0.12
Carabodidae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	3	0.04
Liacaridae	0	0.00	5	0.06	0	0.00	0	0.00	0	0.00	0	0.00	4	0.05
Nanhermanniidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Hermanniidae	0	0.00	18	0.21	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Trichthonidae	1	0.01	0	0.00	4	0.05	0	0.00	0	0.00	1	0.01	0	0.00
Mesoprophoridae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01
Lohmanniidae	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
Gymnodamaeidae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Camisiidae	0	0.00	9	0.11	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Juveniles	44	0.51	124	1.45	76	0.89	97	1.13	21	0.25	12	0.14	26	0.30
Mesostigmata														
Rhodacaridae	110	1.29	266	3.11	1030	12.05	71	0.83	72	0.84	267	3.12	88	1.03

Laelapidae	7	0.08	380	4.45	99	1.16	37	0.43	11	0.13	28	0.33	61	0.71
Ologamasidae	3	0.04	207	2.42	12	0.14	8	0.09	0	0.00	1	0.01	115	1.35
Macrochellidae	0	0.00	0	0.00	32	0.37	0	0.00	1	0.01	0	0.00	0	0.00
Parasitidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Uropodidae	33	0.39	133	1.56	26	0.30	4	0.05	1	0.01	10	0.12	238	2.78
Pachylaelapidae	0	0.00	159	1.86	16	0.19	7	0.08	0	0.00	8	0.09	30	0.35
Polyaspididae	0	0.00	0	0.00	0	0.00	1	0.01	3	0.04	0	0.00	0	0.00
Digamasellidae	8	0.09	91	1.06	0	0.00	0	0.00	0	0.00	0	0.00	121	1.42
Sejidae	7	0.08	0	0.00	16	0.19	0	0.00	0	0.00	0	0.00	0	0.00
Juveniles	89	1.04	346	4.05	74	0.87	44	0.51	55	0.64	34	0.40	55	0.64
Prostigmata														
Cunaxidae	2	0.02	4	0.05	2	0.02	1	0.01	5	0.06	1	0.01	3	0.04
Trombiididae	1	0.01	1	0.01	2	0.02	0	0.00	1	0.01	0	0.00	1	0.01
Chelytidae	0	0.00	0	0.00	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00
Eupodidae	16	0.19	0	0.00	2	0.02	0	0.00	6	0.07	0	0.00	0	0.00
Rhagididae	23	0.27	0	0.00	3	0.04	0	0.00	10	0.12	0	0.00	0	0.00
Astigmata (Hypopus)	0	0.00	0	0.00	4	0.05	0	0.00	0	0.00	0	0.00	0	0.00
Total mites	482	5.64	2428	28.41	1655	19.36	529	6.19	289	3.38	443	5.18	976	11.42
Total mite groups	19		24		22		11		14		13		17	

Key: CO-coffee, C.F-Cypress forest, F-Fallow, H-Horticulture, M-B-Maize-Based, NA-Napier, N.F- Natural forest, P.F-Pine

Table 3: Total and Relative Abundance of Soil Mites(0-5 cm depth) in the Short Rains Season in Oct-Nov. 2007 at Taita.

	CO		**C. F.**		**F**		**H**		**M-B**		**NA**		**N. F.**	
Mite group	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%
Oribatida														
Scheloribatidae	158	2.95	229	4.27	254	4.74	228	4.25	58	1.08	400	7.46	23	0.4
Peloppiidae	0	0.00	4	0.07	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Otocepheidae	1	0.02	10	0.19	0	0.00	0	0.00	0	0.00	0	0.00	2	0.0
Northridae	3	0.06	36	0.67	0	0.00	8	0.15	0	0.00	0	0.00	0	0.0
Neolididae	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Galumnidae	109	2.03	42	0.78	31	0.58	34	0.63	17	0.32	3	0.06	20	0.3
Oppiidae	21	0.39	122	2.28	32	0.60	42	0.78	6	0.11	6	0.11	41	0.7
Pthiracaridae	1	0.02	3	0.06	11	0.21	1	0.02	1	0.02	0	0.00	1	0.0
Eupthiracaridae	0	0.00	2	0.04	19	0.35	0	0.00	1	0.02	0	0.00	0	0.0
Damaeidae	3	0.06	2	0.04	2	0.04	3	0.06	1	0.02	0	0.00	4	0.0
Haplozetidae	8	0.15	63	1.18	28	0.52	27	0.50	0	0.00	3	0.06	6	0.1
Carabodidae	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
Metrioppiidae	10	0.19	0	0.00	4	0.07	1	0.02	0	0.00	0	0.00	0	0.0
Liacaridae	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
Hermanniidae	0	0.00	0	0.00	1	0.02	0	0.00	0	0.00	0	0.00	1	0.0
Mesoprophoridae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.0
Lohmanniidae	2	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Gymnodamaeidae	0	0.00	21	0.39	0	0.00	4	0.07	0	0.00	0	0.00	1	0.0
Eulohmanniidae	4	0.07	0	0.00	5	0.09	0	0.00	0	0.00	0	0.00	1	0.0
Juveniles	72	1.34	299	5.58	149	2.78	138	2.57	55	1.03	161	3.00	53	0.9
Mesostigmata														
Rhodacaridae	24	0.45	164	3.06	90	1.68	45	0.84	58	1.08	43	0.80	17	0.3
Laelapidae	7	0.13	30	0.56	40	0.75	5	0.09	6	0.11	19	0.35	13	0.2
Ologamasidae	24	0.45	158	2.95	4	0.07	3	0.06	2	0.04	1	0.02	9	0.1
Macrochellidae	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00	4	0.07	0	0.0
Parasitidae	0	0.00	0	0.00	0	0.00	5	0.09	0	0.00	0	0.00	0	0.0
Uropodidae	28	0.52	14	0.26	28	0.52	21	0.39	4	0.07	28	0.52	14	0.2
Pachylaelapidae	0	0.00	8	0.15	13	0.24	0	0.00	0	0.00	9	0.17	0	0.0
Polyaspididae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Digamasellidae	0	0.00	6	0.11	7	0.13	0	0.00	0	0.00	0	0.00	0	0.0
Sejidae	0	0.00	2	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Juveniles	47	0.88	221	4.12	87	1.62	82	1.53	89	1.66	86	1.60	26	0.4
Prostigmata														
Cunaxidae	5	0.09	17	0.32	4	0.07	7	0.13	4	0.07	10	0.19	2	0.0
Trombiididae	1	0.02	0	0.00	1	0.02	0	0.00	1	0.02	1	0.02	1	0.0
Chelytidae	0	0.00	0	0.00	1	0.02	0	0.00	2	0.04	2	0.04	0	0.0

Eupodidae	0	0.00	44	0.82	2	0.04	1	0.02	0	0.00	0	0.00	6	0.1
Rhagididae	0	0.00	69	1.29	3	0.06	0	0.00	0	0.00	0	0.00	5	0.0
Bdellidae	1	0.02	2	0.04	0	0.00	0	0.00	1	0.02	1	0.02	0	0.0
Tetrachnoidea	0	0.00	0	0.00	0	0.00	2	0.04	0	0.00	0	0.00	0	0.0
Juveniles	0	0.00	84	1.57	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Astigmata (Hypopus	7	0.13	1	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.0
Total mites	537	10.02	1655	30.88	816	15.22	659	12.29	306	5.71	777	14.50	249	4.6
Total mite groups	20		25		21		18		14		14		21	

Key: CO-coffee, C.F-Cypress forest, F-Fallow, H-Horticulture, M-B-Maize-Based, NA-Napier, N.F- Natural forest, P.F-Pine

Table 4: Total and relative abundance of soil mites (0-5 cm depth) in the Long rain season in April 2008 (2008) at Taita

	CO		**C. F.**		**F**		**H**		**M-B**		**NA**		**N. F.**	
Mite group	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%	Totals	%
Oribatida														
Scheloribatidae	58	0.68	115	1.35	184	2.15	234	2.74	72	0.84	55	0.64	100	1.17
Peloppiidae	0	0.00	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Otocepheidae	1	0.01	12	0.14	0	0.00	0	0.00	0	0.00	0	0.00	5	0.06
Northridae	11	0.13	89	1.04	2	0.02	2	0.02	5	0.06	0	0.00	0	0.00
Neolididae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Galumnidae	36	0.42	74	0.87	13	0.15	0	0.00	13	0.15	3	0.04	24	0.28
Oppiidae	10	0.12	263	3.08	16	0.19	21	0.25	3	0.04	19	0.22	87	1.02
Pthiracaridae	0	0.00	9	0.11	5	0.06	0	0.00	0	0.00	1	0.01	0	0.00
Eupthiracaridae	0	0.00	8	0.09	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00
Damaeidae	9	0.11	25	0.29	15	0.18	0	0.00	10	0.12	0	0.00	4	0.05
Haplozetidae	12	0.14	81	0.95	16	0.19	2	0.02	0	0.00	2	0.02	10	0.12
Carabodidae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	3	0.04
Liacaridae	0	0.00	5	0.06	0	0.00	0	0.00	0	0.00	0	0.00	4	0.05
Nanhermanniidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Hermanniidae	0	0.00	18	0.21	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Trichthonidae	1	0.01	0	0.00	4	0.05	0	0.00	0	0.00	1	0.01	0	0.00
Mesoprophoridae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01
Lohmanniidae	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
Gymnodamaeidae	0	0.00	2	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Camisiidae	0	0.00	9	0.11	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Juveniles	44	0.51	124	1.45	76	0.89	97	1.13	21	0.25	12	0.14	26	0.30
Mesostigmata														

Rhodacaridae	110	1.29	266	3.11	1030	12.05	71	0.83	72	0.84	267	3.12	88	1.03
Laelapidae	7	0.08	380	4.45	99	1.16	37	0.43	11	0.13	28	0.33	61	0.71
Ologamasidae	3	0.04	207	2.42	12	0.14	8	0.09	0	0.00	1	0.01	115	1.35
Macrochellidae	0	0.00	0	0.00	32	0.37	0	0.00	1	0.01	0	0.00	0	0.00
Parasitidae	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Uropodidae	33	0.39	133	1.56	26	0.30	4	0.05	1	0.01	10	0.12	238	2.78
Pachylaelapidae	0	0.00	159	1.86	16	0.19	7	0.08	0	0.00	8	0.09	30	0.35
Polyaspididae	0	0.00	0	0.00	0	0.00	1	0.01	3	0.04	0	0.00	0	0.00
Digamasellidae	8	0.09	91	1.06	0	0.00	0	0.00	0	0.00	0	0.00	121	1.42
Sejidae	7	0.08	0	0.00	16	0.19	0	0.00	0	0.00	0	0.00	0	0.00
Juveniles	89	1.04	346	4.05	74	0.87	44	0.51	55	0.64	34	0.40	55	0.64
Prostigmata														
Cunaxidae	2	0.02	4	0.05	2	0.02	1	0.01	5	0.06	1	0.01	3	0.04
Trombiididae	1	0.01	1	0.01	2	0.02	0	0.00	1	0.01	0	0.00	1	0.01
Chelytidae	0	0.00	0	0.00	3	0.04	0	0.00	0	0.00	0	0.00	0	0.00
Eupodidae	16	0.19	0	0.00	2	0.02	0	0.00	6	0.07	0	0.00	0	0.00
Rhagididae	23	0.27	0	0.00	3	0.04	0	0.00	10	0.12	0	0.00	0	0.00
Astigmata (Hypopus)	0	0.00	0	0.00	4	0.05	0	0.00	0	0.00	0	0.00	0	0.00
Total mites	482	5.64	2428	28.41	1655	19.36	529	6.19	289	3.38	443	5.18	976	11.42
Total mite groups	19		24		22		11		14		13		17	

Key: CO-coffee, C.F-Cypress forest, F-Fallow, H-Horticulture, M-B-Maize-Based, NA-Napier, N.F- Natural forest, P.F-Pine

Family Richness and accumulation curves at Taita Taveta to show sampling efficiency

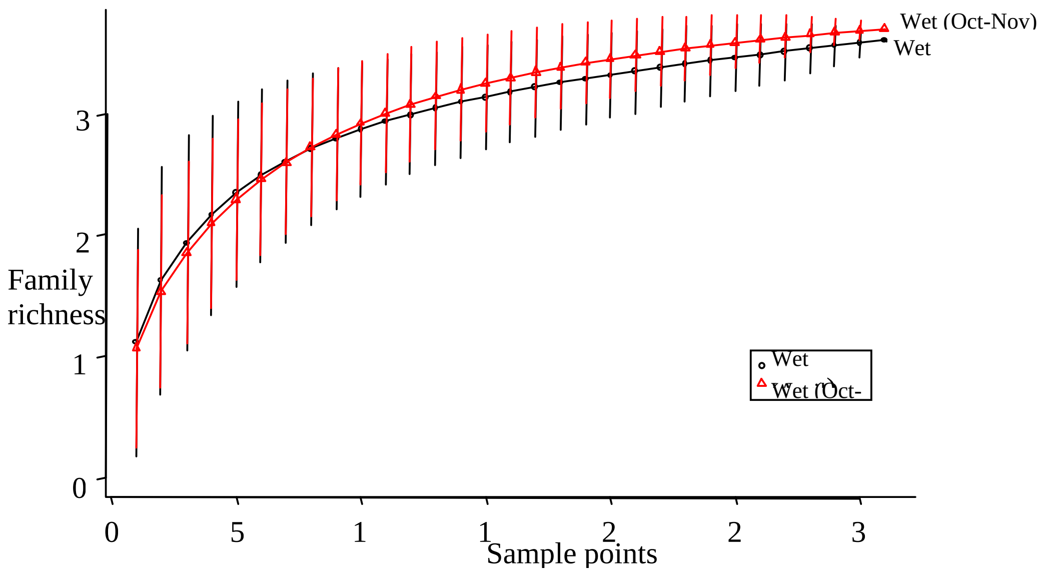


Figure 2: Family accumulation curve of mites from soils in Taita during the short and long rain seasons. Bars on the curve indicate standard error (S.E).

Effect of seasons on abundance, diversity and richness of mites in soils of Taita Taveta

Abundance of mites during two seasons of Oct.-Nov. 2007and April 2008 was 5,360 and 8,547 individuals respectively (Tables 3and 4) and no significant differences were observed between the two seasons.

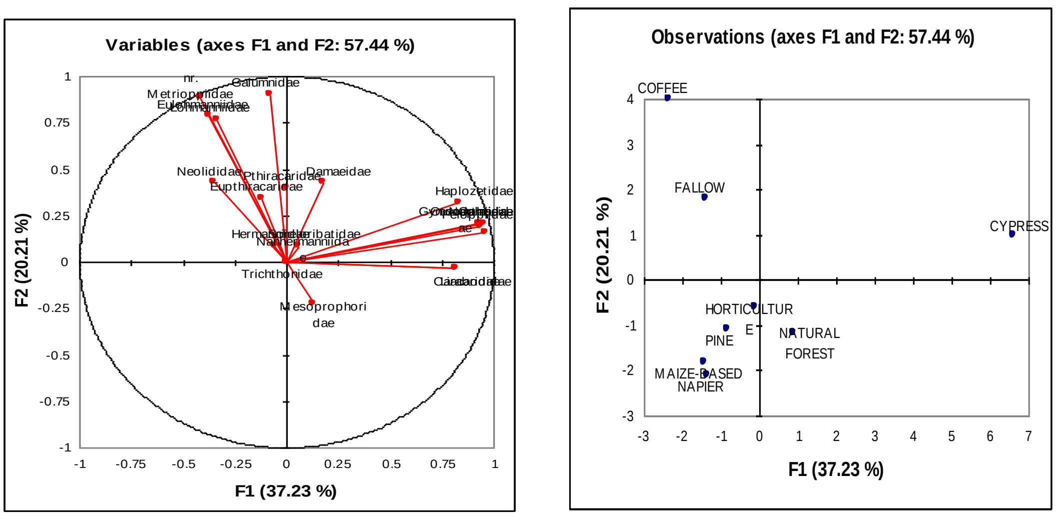
Structure of mites community in soils of Taita Taveta

In the short rains, the oribatid families that associated with plantation forests (pine and cypress) were Nanhermanniidae, Carabodidae, Oppidae, Northridae, Galumnidae, Neolididae, Eupthiracaridae, Liacaridae, Gymnodamaeidae, Pthiracaridae, Damaedae, Camisiidae, Hermanniidae, Oppidae, Haplozetidae and Galumnidae (Figure 3). There were very few families associated with the cultivated LUTs. In the long rains, PCA separated pine and cypress (plantation forests) from the rest of LUT with the following families associating with them; Nanhermanniidae, Carabodidae, Oppidae, Northridae, Galumnidae, Neolididae, Eupthiracaridae, Liacaridae, Gymnodamaeidae, Pthiracaridae, Damaedae, camisiidae, Hermanniidae, Oppidae, and Galumnidae (Figure 4). Plantation forest accounted for 51.2% of LUT effect on Oribatid mites assemblages.

In the short rains, PCA separated agro-ecosystem and natural forest from fallow (intermediate disturbed) and plantation forest ecosystem. The non-oribatid mite families that associated with least disturbed soils under the forest ecosystem (Cypress and pine plantations and the natural forest) were, Sejidae, Ologamasidae, Polyaspididae, Ologamasidae, (Mesostigmata) Cunaxidae, Rhagididae, Trombididae and Bdellidae (Prostigmata). Soils under napier grass supported mainly Trombididae, Chelytidae (Prostigmata) and Uropodidae (Mesostigmata).Rhagididae and Eupodidae (Prostigmata) associated with the cropped soils while Astigmata (hypopus), Chelytidae (prostigmata), Sejidae, Macrochelidae, Rhodacaridae, Pachylaelapidae, Laelapidae, and Digamasellidae, (mesostigmata) associated with soils under fallow (Figure 5). During the Long rains, the PCA separated agro-ecosystems (napier, maize-based, horticulture,) together with fallow from the forest ecosystem (pine forest, natural forest, cypress forest). Rhagididae and Eupodidae (Prostigmata) associated with the agro-ecosystem while Astigmata (hypopus), Chelytidae (prostigmata), Sejidae, Macrochelidae and Rhodacaridae (mesostigmata) associated with fallow. Pine, cypress and natural forest associated with Laelapidae, Ologamasidae, Polyaspididae, Uropodidae, Digamasellidae (Mesostigmata), Trombididae and Cunaxidae (Prostigmata)

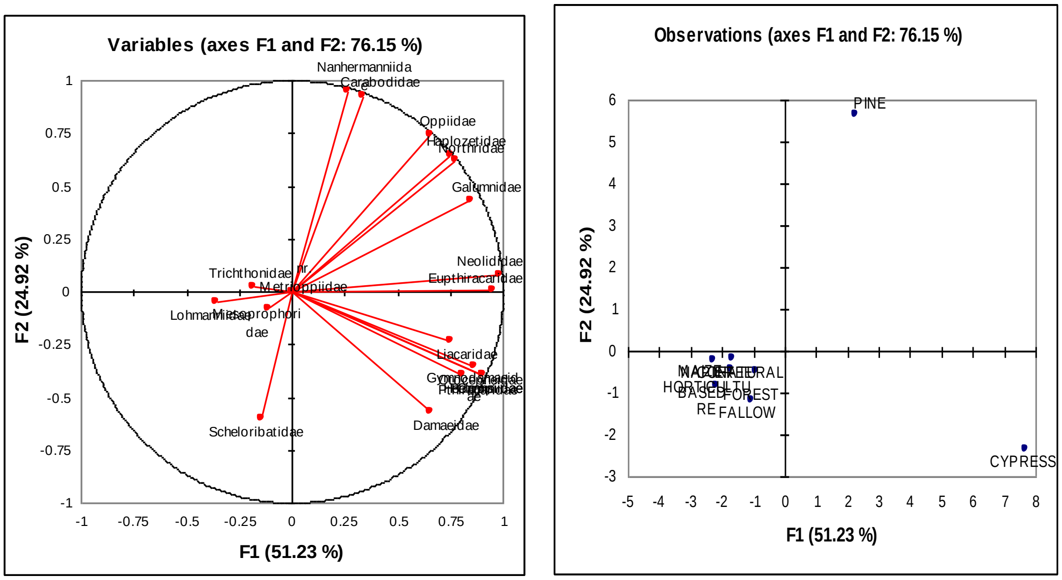
The relationship between LUTs and chemical parameters in soils of Taita

The PCA ordination separated LUT into forest-ecosystems with low pH (acidic) and high C & N (natural forest, cypress, and pine) and agro-ecosystem with moderate to high pH and low C & N (fallow, maize-based, napier, horticulture, coffee) (Figure 7). The combined effect of pH, N & C accounts for 92.43% in grouping of the LUT into agro-ecosystems (High to moderately disturbed) and forest-ecosystems (Lowly disturbed). Cypress and pine had the highest acidity. The mites abundance was higher in cypress and pine LUTs where the soil was more acidic indicating a positive correlation (Table 2).



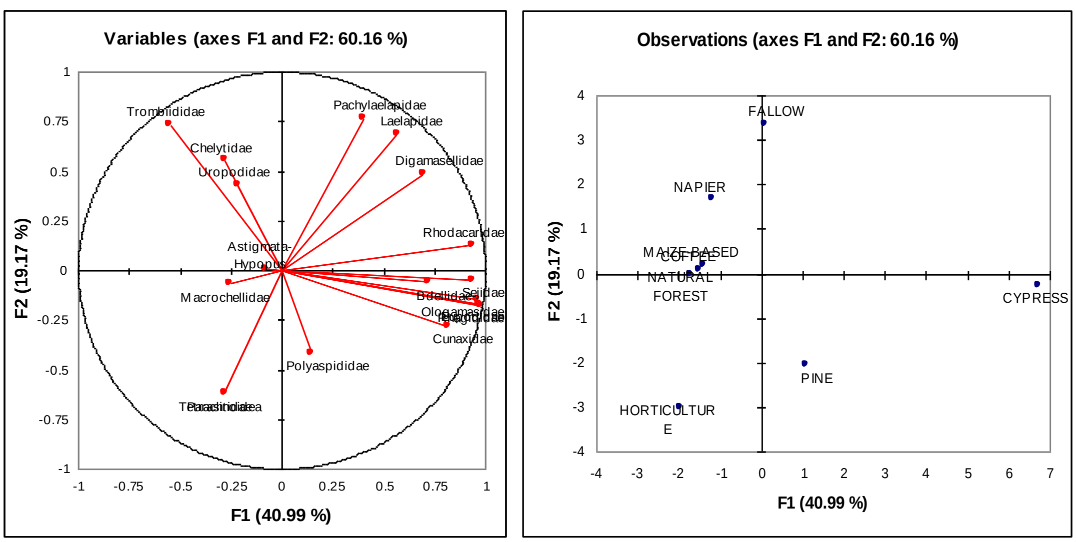
(a) (b)

Figure 3: PCA analysis comparing LUTs and oribatid mite communities in soil during the short rains



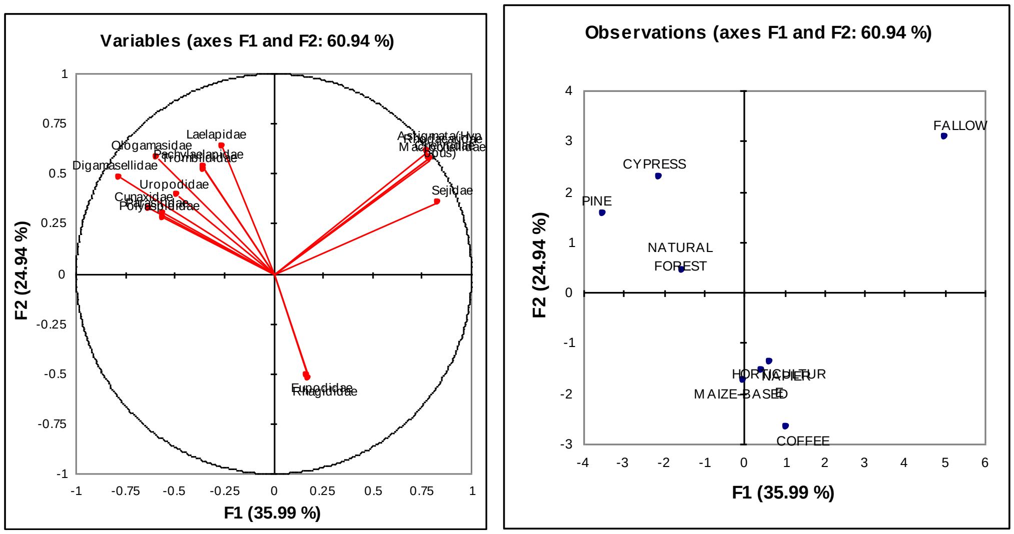
(a) (b)

Figure 4: PCA analysis comparing LUTs and oribatid mite communities in soil during the long rains



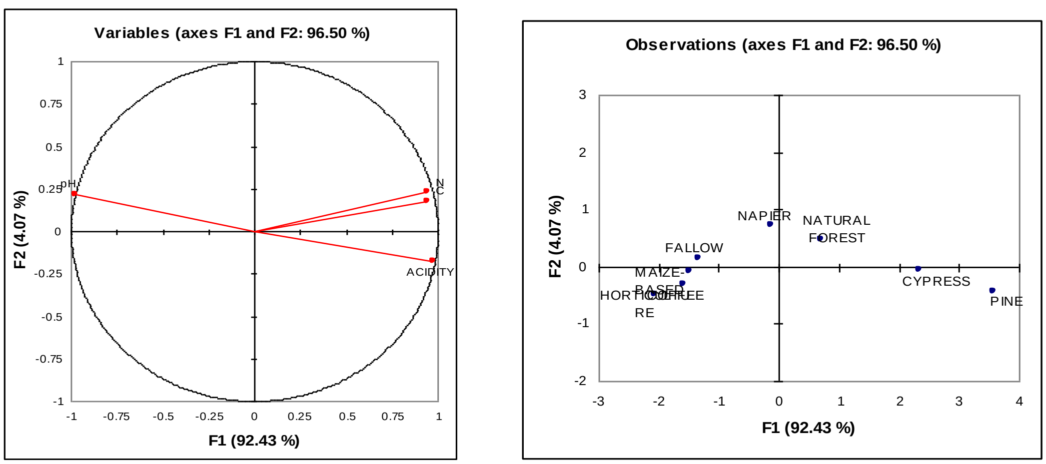
(a) **(b)**

Figure 5: PCA analysis comparing LUTs and the non-oribatid mites in soils of Taita Taveta during the short rains.



(a) **(b)**

Figure 6: PCA analysis comparing LUTs and the non-oribatid mites in soils of Taita Taveta during the long rains.



(a) **(b)**

Fig 7: PCA analysis comparing LUTs and soil chemical parameters at Taita.
C- Carbon, N- Nitrogen, pH- degree of acidity or alkalinity of the soil.

DISCUSSION

It was observed that the diversity and abundance of soil mites tended to vary with the LUTs as demonstrated in other studies carried out in tropical as well as temperate areas of the world (Minor and Cianciolo, 2007; Cianciolo and Norton, 2006; Noti *et al.*, 2003; Badejo and Ola-Adams, 2000; Badejo and Tian, 1999). In this study, soils under cropping systems recorded lower mites abundance and diversity compared to the less disturbed soils under forest ecosystems. This could be attributed to regular cultivation resulting in disturbances. For instances, tillage has been demonstrated to have adverse effects on soil mites with 50% reduction in population immediately after tillage (Hülsmann and Wolters, 1998). In this study, the maize-based and vegetables production systems involve continued cultivation of soil for planting and weeds control and addition of soil amendments (inorganic fertilisers and pesticides) that are likely to have negative effect on soil organisms. Agricultural land have been reported to be low in diversity and richness of soil mites, a factor attributed to strong disturbance of soils due to anthropogenic activity of crops production system (Arroyo and Iturrondobeitia, 2006). Further, Arroyo and Iturrondobeitia, (2006) suggested that traditional agricultural practices such as use of non-organic wastes amendments, inorganic fertilization, use of agrochemical products and burning of crop residues after harvest may have a negative effect on soil leading to biodiversity decrease.

The forest ecosystems (pine and cypress plantations) had higher mite abundance, richness and diversity than cropped soils possibly due to low disturbance which ensured stable litter layer and suitable micro-climate. Rodriguez *et al*., (2006) found arthropod abundance in agroecosystem as well as under zero-tillage to be higher than under conventional tillage due to presence of surface residue. The uncultivated soils with plant residue cover provided a readily available food resource and moderated the effect of extreme temperatures and also reduced the rate of moisture loss from the soil surface (Coleman *et al*., 2002; Bedano *et al*., 2006). In this study the cultivated soils had low nitrogen and carbon content as evidenced by the soil analysis indicating low organic content and hence low food resource for the mites. Conversion of forest ecosystem into cropping systems was expected to affect the soil mites negatively. Moore (1994), found species diversity and functional diversity to be lower in agricultural soils compared to undisturbed native soil and more intensive agriculture impacts diversity more than minimum tillage and integrated practices. Fallow is a land under ecological succession due to recovery from cultivation and hence was found to support high abundance and families' richness of mites. Fallowing and/or shifting cultivation, a common practice in Taita have been demonstrated to stimulate recovery of soil mites (Neher, 1999; Soini, 2005).

Disturbances such as sieving and mixing of soil and litter were found to strongly affect the density and diversity of soil microarthropods (Maraun *et al*., 2003). Recovery of fallow from intensities of physical disturbances such as tillage may explain the high abundance and richness of the mites. Earlier studies indicated abandoned crop land had high abundance of oribatid mites, indicating recovering of soil since termination of agricultural practices (Arroyo and Iturrondobeitia, 2006). Arroyo and Iturrondobeitia, (2006) further stated that forest and pasture plots supported higher diversity of oribatid mites while agroecosystem plots had the lowest diversity and equitability.

The exotic trees such as pine and cypress that were grown in Taita site supported the highest abundance and diversity of soil mites due to high amounts of litter, nitrogen and carbon content indicating a rich food resource base and suitable habitat, these observations agreed with other studies elsewhere (Horwood and Butt, 2000; Maraun and Scheu, 2000, Peterson and Luxton, 1982).

In this study there were no significant difference in the abundance, richness and diversity of soil mites between short rain and long rain seasons. Mites abundance and diversity are reported to differ with seasons with the wet seasons recording higher abundance and diversity compared to the dry periods (Badejo and Akinwole, 2006; Badejo *et al*., 2002; Badejo and Tian, 1999; Badejo, 1990; Purvis and Curry, 1980).

Whereas there are previous studies on soil mites in Kenya, none is available on effect of land use types, seasons and soil chemical parameters on the mites community structure. This study for the first time has come up with families of mites found on various land use types and how the chemical parameters of soil also influence the community structure. A total 37 families were discovered, with 20 of oribatid mites families, 10 mesostigmata families and 7 prostigmata families. The most dominant of the families across the LUTs were Scheloribatidae, Rhodacaridae and Oppidae. Scheloribatidae family has earlier been reported to dominate forest sites (Badejo and Akinwole, 2006; Franklin *et al*., 2005). The Oppidae family was found to be dominant in forest woodland and hence an indicator of such a habitat (Noti *et al*., 1996). Behan-pellentier, (1999) suggested Oppidae as indicator of recent disturbance in both forested ecosystem and agroecosystems. Some of the families that strongly associated with forests were Eupthiracaridae, Pthiracaridae, Carabodidae, Dampfielidae, Otocepheidae, Nanhermanniidae, Northridae, Oppidae, Gymnodamaeidae, Liacaridae and Scheloribatidae (Oribatida). The presence of these families and their high abundance could be an indicator of a more stable habitat with little or no disturbance as well as good resource (food and dwelling places in the litter layers). Oribatid mites especially those with long development times, low fecundity and high adult longevity have been found in forest habitats (Minor and Cianciolo, 2006; Luxton, 1981).

Fallow was dominated by Scheloribatidae (Oribatida), Rhodacaridae, Pachylaelapidae, Laelapidae**,** Digamasellidae (Mesostigmata), Cunaxidae (Prostigmata) and Astigmata (*Hypopus*) and hence the presence of these families could be an indicator of land recovering from disturbance. The presence of Scheroribatidae (Oribatida) and Rhodacaridae (Mesostigmata) in high numbers under fallow is not accidental as Koehler (1999), and Minor and Cianciolo (2007) described Rhodacaridae and Mesostigmata in general to have high population and diversity in such early successional sites due to shorter life cycles. Scheloribatidae have in the past been found in early successional habitats in high numbers due to their relatively high fecundity and short life cycles with 2-3 generations per year (Luxton, 1981; Maraun *et al.*, 2003). Successional habitats such as fallow have also been found to have higher density and diversity of all mite groups after a prolonged period of rest from cultivation (Purvis and Curry, 1980). The family Sejidae (Mesostigmata) was found mainly in fallow and cypress forest. Sejidae in the past has been found in soil rich in humus and organic matter in the tropics (Krantz, 1978) and hence can also be an indicator of high organic content in the soil. Uropodidae (Mesostigmata) was highly dominant in forests showing a prevalence of litter layers.

In general, oribatid mites were found to dominate the forest habitats and were low in the agroecosystems. This was likely due to their preference for organic horizons in the soil (Norton, 1990) largely found in the forest ecosystem as well as lack of disturbance. Disturbance through tillage in the agroecosystem, low fecundity, poor dispersal and inability to utilize short term resources in search habitats could have attributed to their low population (Behan-Pelletier, 1999). The forest ecosystem with pine and cypress had higher oribatid mites and correlated with high acidity and higher organic matter as evidenced by high carbon and nitrogen. This shows oribatid mites have a preference of high soil organic matter and high acidity. St. John *et al*., (2002) and Bedano *et al*., (2006) found the density of oribatid mites to positively relate with soil organic matter while increased soil acidity gave higher dominance of Oribatei (Hagvar and Amundsen, 1981).

CONCLUSION

This is the first study in Kenya on the effect of LUTs on the soil mites abundance and diversity. From the study it has been confirmed LUTs had a significant effect on the abundance, richness and diversity of soil mites and supported unique community structure. Agroecosystems comprising of maize-based system, horticulture and coffee, supported lower soil mites abundance, richness and diversity compared to forest ecosystems and fallow practices. Intensification of the land use through cultivation has hence been demonstrated to negatively affect the soil mites. Further research on LUTs under agroecostems that would conserve soil mites and promote their activity is necessary. Adoption of LUTs that conserve soil mites by the farmers will help promote their ecosystem services. Conversion of natural ecosystems to agroecostems should also be avoided.

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