

Diversity of functional groups of soil fauna in Egyptian habitats

Safwat H. Shakir Hanna¹, Samir I. Ghabbour², Wafai Z. A. Mikhail²,
Hassan M. Sobhy² and Gehane Sultan²

1- Texas Gulf Coast Environmental Data Center (TEXGED), College of Engineering, Prairie View A&M university, P.O. Box 235, Prairie View, TX 77446, USA,

E-mail: safwat_shakir@pvamu.edu or shshakir@pvamu.edu or safwat_shakir@yahoo.com

2- Dept. of Natural Resources, Institute of African Research and Studies, Cairo University, 12613 Giza (Cairo), Egypt, e-mail: gghabbour@aucegypt.edu

ARTICLE INFO

Article History

Received May 19, 2011

Accepted January 20, 2012

Available online: May 1st, 2012

Keywords

Biodiversity

Soil Fauna

Functional Groups

Land-use

Climate Change

ABSTRACT

In the 1970's, under the International Biological Program (IBP), long-term intensive whole ecosystem studies were undertaken in the Mediterranean coastal strip west of Alexandria, the Mariut region (150-200 mm rainfall/year, xero-Mediterranean climate), and in Wadi Allaqi, east of Lake Nasser in the hyper arid Nubian Desert (0-1 mm rainfall/year). Short visits were made to other regions in Egypt to collect soil fauna and examine their populations. The results of these studies can be now undertaken for a more generalized synthesis to compare populations as regards eco-geographical location, climate, soil type, land use, etc. The distribution of species can be ascribed to the interaction of several factors. The emphasis here is on ratios of functional groups in the various habitats of Egypt. Results show that more aridity and increasing temperatures, from north to south, give lower population sizes of soil fauna. The regional biodiversity showed that northwestern region, of a mild winter and relatively higher rainfall is more diverse than the southeastern region. Additionally, on the regional level, the diversity of soil fauna may be affected by the degree of human interference such as agriculture. Some groups, such as Carabidae, disappear from desert regions in the southeast of the country. In some hyper-arid sites, the predator/prey ratio reaches unity, when the expected ratio should be 1:10. New species invade deserts when irrigation water is brought to these lands for reclamation. Within a certain number of years, the reclaimed desert land may become so similar to "old" Delta land, that the process may be called "Deltatisation". The process may take from five up to 20 years, depending on intensity of land use. It is not a surprise that agricultural pests, such as the mole-cricket and some Lepidoptera, are attracted to these "new" lands. Regarding the potential impact of climate change (higher temperatures and more aridity), it is expected that it will act upon soil fauna populations in many different ways, so that the final outcome may take a long time to materialize.

1. INTRODUCTION

Animal ecology evolved in a natural and logical way in the 20th century from the study of species and their responses to various environmental conditions (autecology), while isolated in the lab to ensure standard comparable situations, to the study populations in the field, where they are exposed to a multitude of perpetually variable physical, chemical, and biotic conditions (synecology). Odum (1959) raised this to a higher level by insisting on studying the ecosystem as a whole (ecosystems of various types and ages, and biomes). The period of the International Biological Programme that followed (1965-1975), resulted in a considerable number of studies enumerating species and prevailing environmental conditions in the world's biomes, and trying to find out the relationship between the two sets of data. The utilization of the newly discovered radioactive isotopes was much helpful in this respect (Ghabbour 1968 and 1988). Later, the use of advanced statistical techniques such as discriminant analysis and correspondence analysis (Ghabbour 1991), made it possible to disentangle the preferred environmental conditions for each one of the species present.

When we come to soil fauna, the same pathway of research phases was followed in many countries, beginning in the UK (Kevan 1955, Murphy 1957), Egypt included (Ghabbour 1988). These statistical techniques allowed establishing criteria for priority choices of nature reserves in Egypt, based on the species richness of their soil fauna (Ghabbour and Mikhail 1988), as well as for the environmental characterization of sites, based on the diversity of their soil fauna populations (El-Shishini and Ghabbour 1988). Nevertheless, it is highly significant that Aristotle called earthworms the Earth's guts in some instances, and entrails of the earth in some other instances (Torrey and Felin 1937). He surmised about their function as well as their shape. Darwin (1840

and 1881) was also more interested in elucidating their functions rather than their structure.

At present, the dominant approach in population ecology as a whole, and in soil fauna research in particular, is to investigate the role of a level of population of species intermediate between the autecology of a single species and the structure and reactions of the population (synecology). This is the level of the functional groups, or what members of species in each of the group of species performing the same function would behave under the various environmental conditions under which this group is living. The functional groups of soil fauna populations can be enumerated as such (Ghabbour 1991):

1. Herbivores: which consume living plant tissue (usually roots) and may become plant pests if they reach the limit of unbearable economic damage,
2. Carnivores: which eat or parasitize other animal species,
3. Herbivores: which decompose dead organic matter. There are species specialized in decomposition of plant litter, animal litter, or both.
4. Omnivores: which are capable of using both types of plant and animal food or litter. To make matters simple, these are classified as either herbivores or carnivores, according to their more obvious preferences.

Based on the role of functional groups of soil fauna, more information and predictability can be gained about their importance in soil processes and in maintaining ecosystem equilibrium at large. According to recent studies, the role of functional groups in soil fauna can be enumerated as such:

1. Zoological ripening of soils. Bal L. (1982).
2. Indicators of soil pollution. Eijsackers H. (1983).
3. Maintaining biodiversity functions. Giller P. S. (1996), Wolters V. (2001).
4. Relevance of the Rio-Convention on Biodiversity. Hågvær S. (1998).

5. Dynamics of organic matter and the associated turnover of carbon and other elements. Brussaard L. (1998).
6. Bioavailability of chemicals for risk assessment and management. Reinecke A. J. (2004).
7. Biological agents for sustainable development, Shakir Hanna S. H. (2004).
8. Conservation biology. Decaëns Th. *et al.* (2006).
9. Ecosystem engineering: Berke S. K. (2010), Decaëns Th. (2010).
10. Stability of aboveground and belowground ecosystem functions: Eisenhauer N. and Schädler M. (2010).
11. Biological, chemical and biochemical dynamics during litter decomposition: G. Tripathi G. *et al.* (2010).
12. Decomposition of recalcitrant organic matter. Briones M. J. I *et al.* (2010).
13. Ecosystem resilience after disasters. Xiao Yihua *et al.* (2010).
14. Climate change. Kardol, P. *et al.* (2011).

The present paper, describing the situation of functional groups of soil in the different ecosystems of Egypt, on the basis of the research that had been carried out since 1974, can be used to predict the changes occurring in these groups as a result of climate change. Roughly, and taking into consideration differences in soil type from clay to sand, we assume that a shift of soil fauna populations (with their main three functional groups), from southern hot and dry regions in the south to warm and the relatively more moist regions in the north, can be *a priori* expected. However, we cannot predict this shift will be at which scale and detail without comparing these groups in their present situation.

Soil fauna biodiversity is becoming one of the important topics in agro-ecology due to the role of these creatures in their functionalities in the ecosystem (Shakir 1989; Shakir 1990; Shakir and Dindal 1997). They play an important role in the ecosystems in the decomposition of organic matter and releasing the nutrients back to soil environment. They also play significant role in the nutrient cycling within the ecosystem and environment. Biodiversity measurements

of soil fauna can be evaluated by the number of species existing in the communities, density, biomass and their distribution within the communities and the frequencies of species in their communities. There are many measurements of biodiversity. However, the role of biodiversity in an ecosystem is an indicator of its health. The true significance of biodiversity includes the ecosystem richness in its biotic structure and its abiotic materials. It is noted that the majority of animals in terrestrial habitats are invertebrate members of the decomposers (Hansen 2000). The soil is a highly interactive system with one species potentially affecting others either positively or negatively. For instance, the earthworm *Eisenia fetida* inhibited the formation of stable aggregates by the earthworm *Lumbricus terrestris* (Hamilton and Dindal 1989). Strong predator pressure may affect the density and distribution of the collembolan species *Heteromurus nitidus* (Salmon and Ponge 1999). The potential effect of associated diversity in soil implies that so-called redundant species may gain functional significance by interacting with functionally important species. Elimination of redundant species may affect the steepness of the relationship between species diversity and function by modifying step depth (via changes in probability of losing important species) or step height (via changes in the performance of important species) or both (Wolters 2001). The term biodiversity means includes all levels of biological complexity from the species itself in the form of living in the ecotype, its life cycle and its physiology and behavior to the more complex species richness and their interactions in the ecosystem (i.e., the food-web relationship).

The present paper will explore the following objectives: 1) analysis of soil macro-fauna diversity in Egypt in different types of micro-ecosystems; 2) analyses of regional diversity of soil fauna in Egypt using the new technology of Geographic Information System (GIS) [ESRI 1996] and 3) use of the Spatial Analysis Model (SAM) of GIS to explore the impact of land-use on

soil fauna diversity and to predict the distribution of soil fauna diversity across Egyptian ecological and land-use regions.

2. MATERIAL AND METHODS

2.1. The Study Sites

Soil fauna were collected from different sites and habitats. These habitats represent the desert environment ranging from the natural habitats to wide land-use practices in Egypt in order to study the regional diversity. These sites were: a) The Coastal Mediterranean desert sites in Mariut Region West of Alexandria (i.e. Omayed and Gharbaniat), Rafah on the North Sinai coast, Balteem on the Delta Coast (Ayyad and Ghabbour 1977; Ayyad and Ghabbour 1986 a; Ghabbour and Shakir 1980, 1982a, 1982b, 1982c; Mikhail 1987, Mikhail 1992, 1993b, 1998); b) Reclaimed desert sites in Middle Egypt at Salihya, Khatataba, Fayoum (Zeidan and Mikhail 1993), Wadi El-Assiuty (Mikhail and Sobhy 1992a, 1992b, 1992c); c) South Sinai Region in Hammat Pharoan, Gebal Mousa, Wadi El Arabien, Ras Mohamed, Neama Bay (Ayyad and Ghabbour 1986a, 1986b), South Eastern Desert in Wadi Allaqi, Wadi Qulieb, and Dihmit farm near the shores of lake Nasser. The soil fauna data in this study were extracted from many authors as mentioned above. The following features characterize these sites: 1) the high aridity and low rainfall; 2) the maximum rainfall in these areas varies between 0.76 mm/year (inland) to 180 mm/year (along the coastal areas of the Mediterranean); 3) the vegetation types are characterized by sand-dune vegetation along the coastal areas of the Mediterranean, salt marsh vegetation and the desert agro-ecosystems crops (i.e. rain-fed crops to irrigated crops as explained by Ghabbour and Shakir 1982a, 1982b, 1982c, and Ghabbour *et al.*1985). The present study gives a summary of some of the more pertinent analyses that were carried out for habitat classification in Egypt, using soil fauna populations as indicators (Ghabbour 1986, 1988; El-Shishiny and Ghabbour 1988).

2.2. Methods of Sampling Soil Fauna

a) The Sieving Method:

This method was described earlier by Ghabbour *et al.*(1977) and was used mainly in the habitats with friable sandy soils. Briefly, it consists of digging the soils under the canopy of the shrub selected for sampling and passing it through a 1-mm sieve, and continue digging until animals and litter are no longer obtained in the dugout soil. A few extra sieving are passed through to ensure that the soil core under the canopy has been completely sampled. This method was used to collect soil animals from under: *Lygos reatam*, *Thymelaea hirsuta*, *Lycium shawii*, and *Jasonia candicans* shrubs at Gharbaniat (Ghabbour *et al.*1977, 1985), *Anabasis articulata* and *T. hirsuta* shrubs at Omayed (Ghabbour *et al.*1984, 1985), *T. hirsuta* shrubs at the Mariut frontal plain (Ghabbour and Shakir 1980; Ghabbour *et al.*1985); fig orchards in the littoral sand dunes at Omayed (Ghabbour and Shakir 1982b; Ghabbour *et al.*1985), *A. articulata* and *T. hirsuta* shrubs under different grazing pressures at the Omayed biosphere Reserve (Cancela da Fonseca *et al.*1984), and *Alhagi maurorum* and *Silene succulenta* shrublets of the sandy soils of northern Delta coast at Balteem (Mikhail 1987). Population density of soil fauna is expressed as individuals/m².

b) The Hand Sorting Method:

This method was used in sandy loamy soils. Ten soil quadrates (50 x 50 x 50 cm deep) were randomly selected from the farming systems listed below. Hand picking of fauna was done carefully in soil dug out from whole quadrates. Samples of soil animals were collected by this method from irrigated farms, hard soil, and bulky soils such as irrigated vineyard (Ghabbour and Shakir 1983); dry farming olive (Ghabbour and Shakir 1984), and irrigated field crops (Ghabbour and Shakir 1982 c). The population density of soil fauna is expressed as individuals/m².

c) Pitfall Trap Method:

The pitfall trap method (Southwood 1978) is laid in the soil by digging a hole in the ground deep enough to take the whole tin can or jar laid in the soil. A 4% Formalin

solution with detergent is placed in the bottom of the trap (since alcohol evaporates rapidly), in order to cause rapid death and thus prevent the animals from eating each other, or escaping. Pitfall traps were placed in selected areas at dusk on one day, kept open overnight and the animals collected the morning of the next day. This method was used for surveying surface-active soil animals at: Wadi El-Assiuty area (Ali *et al.* 1985), Fayoum (Zedan *et al.* 1993), Rafah at Northern Sinai (Mikhail 1998), Wadi Allaqi (Mikhail and Sobhy 1992 a), Wadi Quleib (Mikhail and Sobhy 1992 b), and Dihmit farm east of Lake Nasser (Mikhail and Sobhy 1992 c). Population density of soil fauna is considered in reality in this case as "activity density" (Kromp 1990; Mikhail 1993 a) and is expressed as individuals per pitfall trap.

In the above three methods that were used in collecting soil fauna, it was found that no major significant differences in the collected soil fauna in respect to the area or the volume of soil. Further, several studies and statistical analyses were carried out in the 1980s and 1990s to find if the difference in sampling methods of desert soil fauna (soil sieving and pitfall traps) affect the validity of synthetic comparisons, have shown that this difference has little effect if any on the validity of comparisons, as given by Ghabbour *et al.* (1985), Ghabbour and Mikhail (1985), Ghabbour *et al.* (1988) and Ghabbour and Mikhail (1993a, 1993b). Furthermore, studies on soil arthropods in the early 2000s using the pitfall trap method showed similar results (Santos *et al.* 2006).

2.3. Data Treatment

The statistical methods used in the present study for classification of soil fauna populations are correspondence analysis (CA) and ascending hierarchic classification (AHC). Information about these methods can be found in some of the more recent publications on the subject (Roux 1985, 1987; Escofier and Pagès 1990; Howard 1992). The computer calculations of CA and AHC were carried out using the SYSTAT program (SYSTAT 1998). Ecological

diversity as described by Cancela da Fonseca (1991) was calculated using the Shannon-Wiener index of diversity, H (Deshmukh 1986). Intra-habitat (H_a), whole-habitats (H_y) and inter-habitats ($H_B = H_y / H_a$) diversities (all measured with Shannon-Wiener index H) were also considered (Whittaker 1972; Cancela da Fonseca 1984), as well as the relative intra-habitat diversity ($H_p \% = H_y / H_a$). The Simpson index of diversity, D , was also calculated as described in Wallwork (1976) and Deshmukh (1986). Further, the taxa as presented in table 1, were used in calculations of taxa diversity and other indices.

In addition to the above statistical methods, the trellis diagram method using Renkonen numbers was used as described by Mountford (1961) and Wallwork (1970). Trellis diagram and other diversity indices were calculated through a programs developed at the College of Environmental Science and Forestry, State University of New York in 1981 and improved in 1985, 1986 and 1987, using CMS system including the participation of first author (SHSH) in developing these programs. The first author also, has transferred these programs to work and to function on PC computers using FORTRAN Language. The trellis diagram method helped in evaluating the soil fauna similarities in different regions in Egypt.

The Geographic Information System (GIS) was used to explain the distribution of soil fauna functionality groups in Egypt. GIS software can help visualize, explore, query and analyze data geographically, especially the Spatial Analysis Model (SAM) [ESRI 1996a, 1996b]. Spatial Analyst Model (SAM) helps for better understanding spatial relationships such as in our study for soil fauna functionality groups, in relation to the ecological parameters in different geographical regions in Egypt.

3. RESULTS

Soil fauna population densities in different regional habitats in Egypt were collected from twenty-one sites. The analyses of these densities were distinguished into different functionality

groups, namely: herbivores, carnivores and detritivores.

The soil fauna that characterized the northwestern coastal zone of the Mediterranean on the littoral dunes were Pseudoscorpiones, *Scolopendra*, antlions, Dictyoptera, Scarabaeidae, and Curculionidae. However, the free grazing sites were characterized by scorpions, Diptera, Tenebrionidae, Galeodidae, Thysanura, snails, Lepidoptera and Carabidae. A group of taxa composed of isopods, spiders, Formicidae and other minor groups of Coleoptera and Hymenoptera, Heteroptera, ticks, Geophilomorpha and Homoptera were constitute a transitional fauna in rainfed and irrigated farm sites. On the other hand, the irrigated farms were invaded by different groups of soil fauna such as earthworms, Orthoptera and Dermaptera.

The soil fauna that characterized the Middle Egypt region were Lepidoptera, Tenebrionidae, Formicidae and Orthoptera. The most common taxa that were associated with the southeastern region of Egypt near Aswan were Buprestidae, Chrysomelidae, Opilionidae and Thysanura, Pompilidae and Dermaptera. The taxa of soil fauna that characterized the south of Sinai region were Formicidae, Diptera, and Carabidae.

The following is the characterization of soil fauna in the different regional habitats in Egypt according to functional groups (Tables 1 and 2).

- A) Soil fauna at the Coastal Mediterranean Natural Desert Ecosystems: Soil fauna under the natural habitats in the coastal Mediterranean desert ecosystems (i.e. at Gharbaniat, Omayed, Rafah, and Balteem) were characterized by detritivores 88.77%, herbivores 2.50%, and carnivores 8.73%.
- B) Soil fauna at the Coastal Mediterranean desert ecosystems under different grazing pressures: Soil fauna at the Coastal Mediterranean desert ecosystems habitats under different transects of grazing pressure (i.e. at Omayed) were characterized by detritivores 87.50%, herbivores 2.70%, and carnivores 9.80%.
- C) Soil fauna at the Coastal Mediterranean desert agro-ecosystems under different agricultural regimes: Soil fauna at the Coastal Mediterranean desert agro-ecosystems under different agricultural regimes varied from rain-fed to irrigated system (i.e. at Gharbaniat, Omayed, and Burg-el-Arab) were

characterized detritivores 80.5%, herbivores 13.2%, and carnivores 6.28%.

- D) Soil fauna at the reclaimed desert sites at the fringes of the Delta and Middle Egypt: Soil fauna at the reclaimed desert sites at the fringes of the Delta and Middle Egypt (i.e. at Salihya, Khatataba, and Fayoum) were characterized by detritivores 60.98-89.54% with an average of 80.75%, herbivores 4.87-6.18% with an average of 4.46%, and carnivores 5.85-34.15 with an average of 14.79%.
- E) Soil fauna at south Sinai Peninsula of Egypt: Soil fauna density at the eastern desert sites in Sinai in Egypt (i.e. at Hammat Pharoan, Gebal Mousa, Wadi-el-Arabien, Ras Mohamed, and Neama Bay) were characterized by varied faunal taxonomical groups from different functionalities (i.e. detritivores 7.1-100% with an average of 71.98 %, herbivores 2.0-78.0% with an average of 22.99, and carnivores 0.0-14.3.0% with an average of 5.14%).
- F) Soil fauna at the south eastern desert in Wadi Allaqi, Wadi Qulieb, and Dihmit farm: Soil fauna at the southeastern desert of Egypt south of Aswan were characterized by lower percentage in the herbivores to be between 2.4-4.4 %. The other trophic groups like detritivores were in the range of 96% and carnivores were in the range 1.1-1.3%. It seems that in this area with very low rainfall and high temperatures, the distribution of soil fauna functional groups may keep the change in a constant situation due to the prevailing these environmental factors. In addition, It is noticeable that herbivores are accompanied the introduction of agricultural crops in any reclaimed desert areas.

In general, analysis of the distribution of soil fauna across the regions in Egypt indicated that the soil fauna in areas of reclaimed desert tend to change in structure according to the functionality and habitat characteristics (i.e. the soil fauna in the natural desert tend to be detritivores (80-98%) rather than herbivores; however, in the reclaimed desert with the introduction of agriculture in these areas the soil fauna tend to have more herbivores (6%-12%) rather than detritivores. This means that a relatively minor shift in percentage from detritivores to herbivores in the newly reclaimed areas. Accordingly, this can be happened with introduction of agricultural crops and introducing new pests in these areas.

Table 1: Population density of soil fauna in twenty one Egyptian sites representing different geographical regions

Taxa	Type	G	M	O	K	Y	I	DH	WAL	WQ	B	R	HP	RM	NB	WAR	GM	S	FA	RF	SAL	KH
Earthworms	D	0.00	0.00	0.00	0.00	0.55	14.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Snails	H,D	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Isopoda	D	1.66	3.68	0.38	0.01	3.28	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	5.00
Spiders	C	0.34	1.24	0.24	4.70	0.61	2.41	0.05	0.04	0.04	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.70	9.00	20.00	18.00
Opilionidae	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scorpions	C	0.00	0.04	0.06	0.04	0.00	0.00	0.00	0.04	0.01	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Galeodidae	C	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pseudoscorpions	D	0.07	0.00	0.00	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ticks	D	0.00	0.12	0.00	0.17	0.03	0.00	0.00	0.00	0.02	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00
Millipides	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00
Geophilomorpha	C	0.05	0.07	0.00	0.06	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scolopendra	C	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanura	D	0.00	0.24	0.00	0.96	0.04	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	265.00	2.00	0.00
Orthoptera	H,D	0.00	0.00	0.00	0.00	0.04	3.92	0.03	0.03	0.01	0.00	0.12	0.00	0.00	0.00	0.00	3.00	0.23	0.07	12.00	4.00	5.00
Dictyoptera	D	10.50	11.56	6.13	5.15	2.13	0.02	0.00	0.00	0.00	6.90	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dermaptera	D	0.00	0.00	0.00	0.00	0.01	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heteroptera	H	0.36	2.56	0.07	2.97	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Homoptera	H	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	H	0.00	0.00	0.00	0.00	1.34	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.00	0.00	3.00
Antlions	C	1.14	3.38	0.52	5.09	0.43	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00
Sphécidae	D	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Formicidae	D	0.28	3.30	3.33	11.37	3.07	18.73	3.98	5.42	4.14	0.00	4.09	500.00	0.00	0.00	0.00	0.00	13.52	1.16	159.00	113.00	190.00
Pompilidae	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Hymenoptera	H	0.02	0.00	0.05	0.00	0.26	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diptera	D	0.35	1.44	0.12	0.91	0.55	0.17	0.00	0.00	0.10	0.00	0.17	0.00	4.00	4.00	0.00	1.00	3.93	0.05	80.00	0.00	44.00
Lepidoptera	H	0.20	0.60	0.12	0.00	0.26	0.58	0.01	0.10	0.14	0.00	0.10	0.00	2.00	0.00	1.00	5.00	1.30	0.03	53.00	0.00	4.00
Tenebrionidae	D	5.25	15.42	1.96	2.54	7.66	2.17	0.02	0.56	0.83	5.36	0.72	0.00	0.00	0.00	0.00	0.00	3.80	0.03	0.00	14.00	18.00
Scarabaeidae	D	6.12	9.08	0.38	2.37	2.12	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
Carabidae	C	0.15	1.30	0.58	0.24	0.25	0.85	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.00	0.53	0.00	5.00	0.00	0.00
Anthicidae	H	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coccinellidae	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	1.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00
Buprestidae	D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chrysomelida	H	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Curculionidae	H,D	0.54	0.00	0.16	2.05	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00
Other	H,D	0.00	2.80	0.00	0.10	0.46	0.49	0.00	0.00	0.00	0.00	0.00	6.00	2.00	0.00	7.00	3.00	0.00	0.00	0.00	0.00	0.00

G=Gharbaniat, O=Omayed including free grazing, R=Rafah, B=Balteem,

M=Mariut frontal plain, K=Complete protection from grazing, Y=Dry farming, I=Irrigated farming

FAandRF=Fayoum reclaimed desert areas for agricultural crops

KH= Khatatba, SAL=Salhyia,S=Wadi el Assiuit,

HP=Hammat Pharoan, GM=Gebal Mousa, WAR=Wadi el Arabien, RM=Ras Mohamed

NB=Namema Bay, WQ=Wadi Quleib, WAL=Wadi el Allaqi, DH=Dihmit farm

Table 2: Regional functional groups of soil fauna in Egypt

Sites	Herbivores %	Detritivores %	Carnivores %
Coastal Mediterranean Region of Egypt			
G	2.14	91.57	6.20
O	2.70	87.50	9.80
R	3.91	89.30	6.79
B	1.23	86.71	12.05
K	13.28	60.76	25.96
Y	14.50	79.92	5.58
I	11.87	81.16	6.97
Middle of Egypt Region			
FA	4.87	60.98	34.15
KH	4.18	89.54	6.28
SAL	2.59	84.51	12.90
S	6.18	87.97	5.85
South Sinai Region Eastern of Egypt			
HP	1.18	98.62	0.20
GM	78.57	7.14	14.29
WAR	12.50	87.50	0
RM	22.72	66.66	11.21
NB	0.00	100.00	0.00
Southern Region of Egypt			
WQ	4.39	95.59	1.09
WAL	2.56	96.16	1.28
DH	2.42	96.35	1.22

G=Littoral sand dunes and Mariut frontal plain, O=Omayed free grazing, R=Rafah, B=Balteem

K=Complete protection from grazing, Y=Dry farming, I=Irrigated farming

FA=Fayoum reclaimed desert areas for agricultural crops

KH= Khatatba, SAL=Salhyia, S=Wadi el Assiuit, Y

HP=Hammam Pharoan, GM=Gabal Mousa, WAR=Wadi el Arabien, RM=Ras Mohamed

NB=Naema Bay, WQ=Wadi Quleib, WAL=Wadi el Allaqi, DH=Dihmit farm

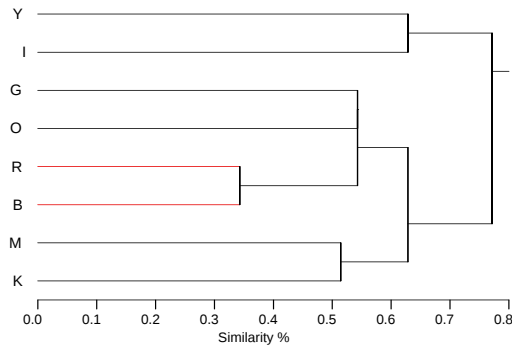
3.1 SPECIES DIVERSITY

Biodiversity indices such as Shannon and Simpson (Table 3) indicated that the sites dominated in the natural vegetation have the highest values of diversity of soil fauna rather than the agricultural or reclaimed desert sites (i.e., the average H_a value is 1.66 for all natural sites and 1.10 for all reclaimed desert areas). In this respect, further dissecting the sites into different regions such as the coastal Mediterranean, Middle Egypt, South Sinai, and the southern region, we found that the H_a diversity has high values in the coastal areas in northern Egypt (less arid conditions) and lower values in the southern Egypt (hyper-arid conditions where the maximum rainfall is only 0.7 mm/year) [Tables 1-3]. In differentiating soil fauna taxa into regional areas, the trellis diagrams (Figs. 1-2) in the Mediterranean

coastal region indicated that the soil fauna of Rafah and Balteem are most similar, and the Garbaniat site can be related to them. However, the Omayed site is far different from the other sites. This may be due to the bit higher rainfall or the low intensity of agricultural practices and of grazing, which may affect the diversity of soil fauna. On the other hand, the trellis diagram and correspondence analysis in the southern region indicated that the natural areas are similar to one another and are different from the agricultural sites (Figs. 2-6). In the southern Sinai region, the soil fauna of Gebal Mousa is dissimilar to the other sites (i.e. Naema Bay, Ras Mohamed, Hammam Pharoan and Wadi El Arabien). It seems that soil fauna along the Suez Gulf in southern Sinai are of higher similarities and differ from the inland fauna.

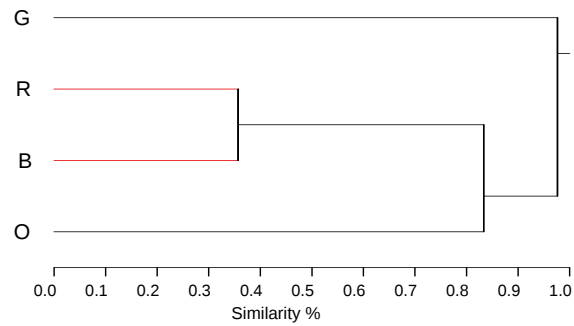
Table 3: Number of groups (S), number of individuals (N), intra-habitat diversity (H_a), inter-habitats diversity (H_b), relative intra-habitat diversity (H_p %) and Evenness ($J' = H_a / H_{\max}$) in different sites and different regions

Sites	S	N	H_a	H_b	H_p %	Simpson Index	J'
Coastal of Mediterranean Region of Egypt							
Dry-Farming	20	24.00	2.21	0.79	126.07	0.16	0.74
Protected Plots	17	38.95	2.15	0.82	122.65	0.15	0.76
Mariut Frontal Plain	17	57.17	2.14	0.82	122.08	0.16	0.73
Omayed	17	14.42	1.77	0.99	100.97	0.26	0.62
Gharbaniat	17	18.78	1.67	1.05	95.27	0.32	0.59
Irrigated farming	14	46.85	1.66	1.06	94.69	0.27	0.63
Balteem	6	14.68	1.22	1.44	69.59	0.36	0.68
Rafah	8	5.60	0.99	1.77	56.47	0.55	0.48
Middle of Egypt Region							
Fayoum	7	2.05	1.04	1.69	59.33	0.44	0.56
Fayoum(reclaimed desert areas for Agriculture)	10	623.00	1.54	1.14	87.85	0.47	0.52
Khatatba	8	287.00	1.16	1.51	66.17	0.47	0.56
Salhiya	7	223.00	1.25	1.40	71.31	0.36	0.65
Wadi El Assiuty	10	24.77	1.43	1.23	81.57	0.35	0.62
South Sinai Region Eastern of Egypt							
Hammat Pharoan	3	507.00	0.92	1.91	52.48	0.43	0.84
Gebal Mousa	5	14.00	1.49	1.18	85.00	0.24	0.93
Wadi el Arabien	2	1.00	0.38	4.61	21.68	0.78	0.54
Ras Mohamed	4	9.00	1.04	1.69	59.33	0.37	0.95
Neama Bay	1	4.00	0.00	0.00	0.00	0.32	0.00
Southern Region of Egypt							
Wadi Quleib	12	5.45	0.88	1.99	50.20	0.60	0.35
Wadi Allaqi	10	6.26	0.56	3.13	31.95	0.76	0.24
Dihmit farm	7	4.11	0.19	9.23	10.84	0.94	0.10
All Habitats S,N, H_a	31	798.09	1.75				



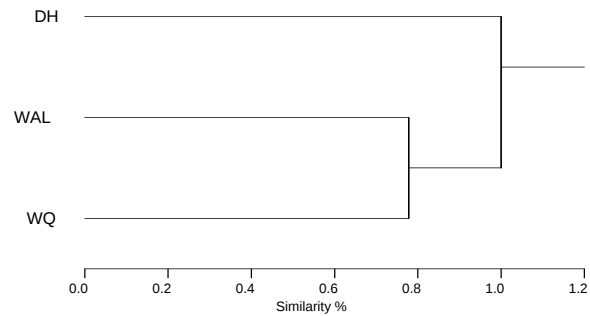
Y= Dry farming field crops, I=irrigated field crops in Mariut area, G= Littoral sand dunes at Gharbaniat, O=Free grazing at Omayed, M=Mariut frontal plain, K=Complete protection from grazing at Omayed, R=Littoral sand dunes cultivated with peach at Rafah, Northern Sinai, B=Littoral sand dunes at Balteem

Fig. 1: Trellis diagram-showing similarity of soil fauna taxa in different sites across the Coastal Mediterranean natural littoral sand dunes, free grazing, varied degree of grazing, and agricultural irrigated and dry farming field crops



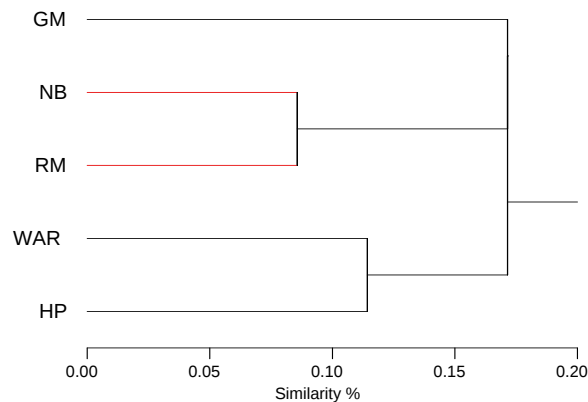
G= Gharbaniat, R= Rafah, B=Balteem, O=Omayed

Fig. 2: Trellis diagram-showing similarity of soil fauna taxa in different sites across the Coastal Mediterranean natural littoral sand dunes



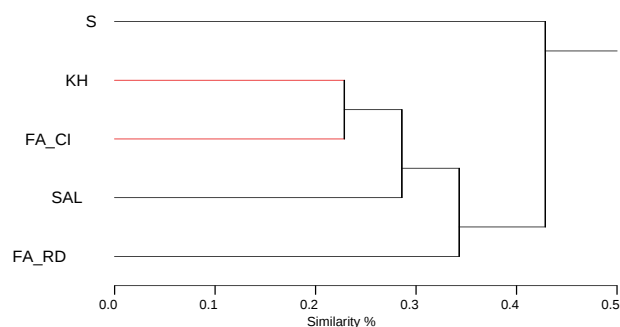
WQ = Wadi-El-Quleib, WAL = Wadi-Allaqi, DH = Dihmit farm (*ferme*)

Fig. 3: Trellis diagram-showing similarity of soil fauna taxa in different sites across the South Eastern Aswan Region.



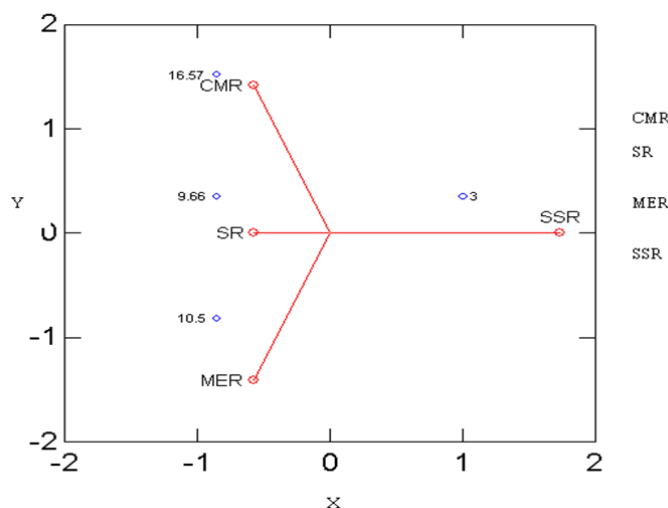
HP = Hammat Pharoan, WAR = Wadi El Arabie, NB= Neama Bay, RM=Ras Mohamed GM= Gebal Mousa.

Fig. 4: Trellis diagram-showing similarity of soil fauna taxa in different sites across the South Eastern Sinai.



S= Assiut, KH=Khatatba, SAL= Salhyia , FA_CI= Cotton field treated with insecticides in Faiyum (*Champ de cotton soumis aux insecticides*), FA_RD= Reclaimed desert areas in Faiyum (*desert bonifie pres du Faiyum*).

Fig. 5: Trellis diagram-showing similarity of soil fauna taxa in different sites across the region of middle of Egypt in Faiyum, Salhyia, Khatatba and Assiut



CMR = Coastal Mediterranean Region of Egypt

SR= Southern Region of Egypt

MER = Middle of Egypt Region

SSR= South Sinai Region East of Egypt

Fig. 6: Graphic representation of application of correspondence analysis (CA) method describing the relationship between soil fauna populations in different regions in Egypt

Generally, using the diversity indices such as intra-habitat diversity, H_a , inter-habitat diversity, H_B , the relative intra-habitat diversity, $H_p\%$, for each of the twenty one sites presented in Table 3, gives a true picture of the classification of the soil fauna into regional ecological habitats and land-use practice zones. When the GIS system was used in differentiating zones of soil fauna diversity, the results indicated that the

Northern coastal area has the highest diversity indices and the southern part of Egypt has the lowest. In addition, GIS indicated varied degrees of differentiation between the natural sites and the reclaimed desert areas, as shown in Figs. 7-10. (i.e., higher diversity is in the natural sites and lower diversity is in the agricultural areas).

3.2 FUNCTIONAL GROUPS DIVERSITY

Analysis of soil fauna functional groups in different regions of Egypt using GIS showed that in general, herbivores are dominant in the reclaimed desert areas. Herbivores varied between 2% and 14% of the taxa in the agricultural areas. Detritivores represent

approximately between 70% and 90% in agricultural areas. On the other hand, carnivores varied between 1% and 35% of the taxa in the studied regions in Egypt (Figs. 7-10). Further, there are variations in functionality groups of soil fauna in the other types of land-use.

Soil Fauna Herbivores Group

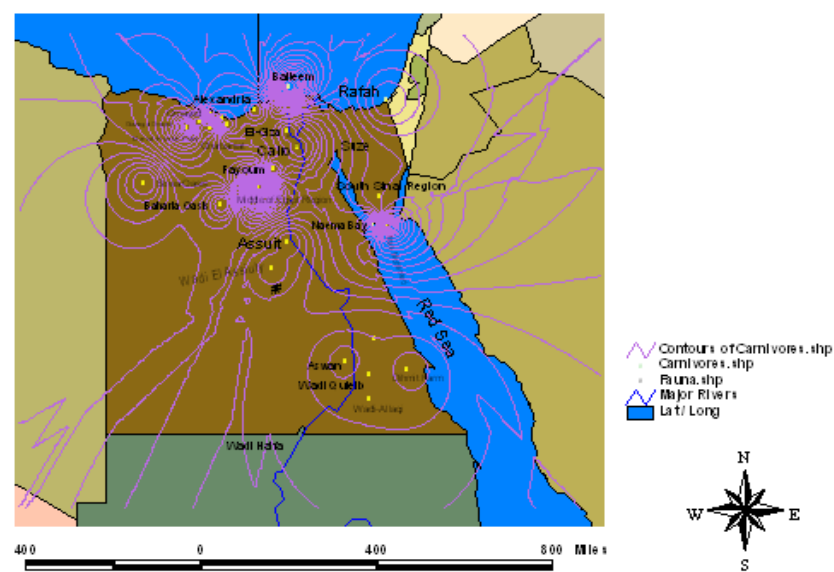


Fig. 7: Distribution map of herbivore soil fauna functional group in Egypt.

Notice: The purpose of representing the data of soil fauna is to show the intensity of data around the selected studied sites.

Soil Fauna Carnivores Group

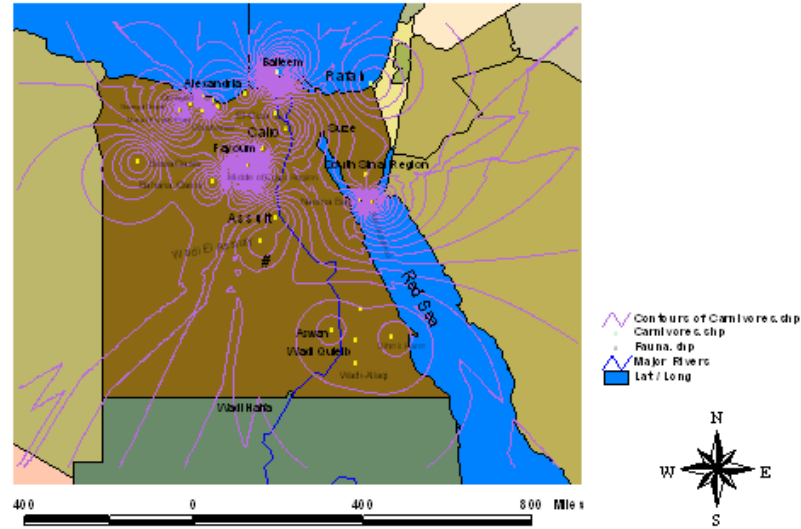


Fig. 8: Distribution map of carnivore soil fauna functional group in Egypt

Soil Fauna Detritivores Group

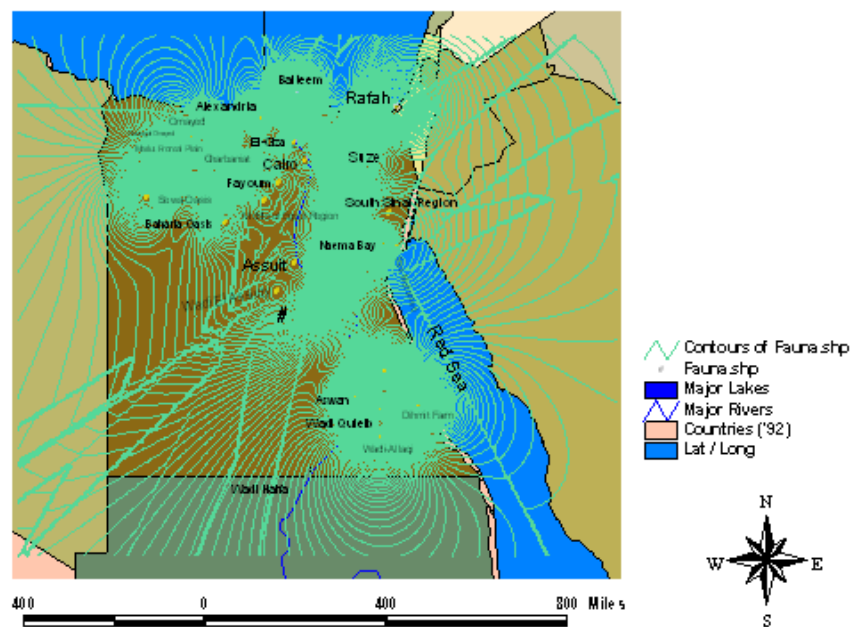


Figure 9 - Distribution map of detritivores soil fauna functional group in Egypt

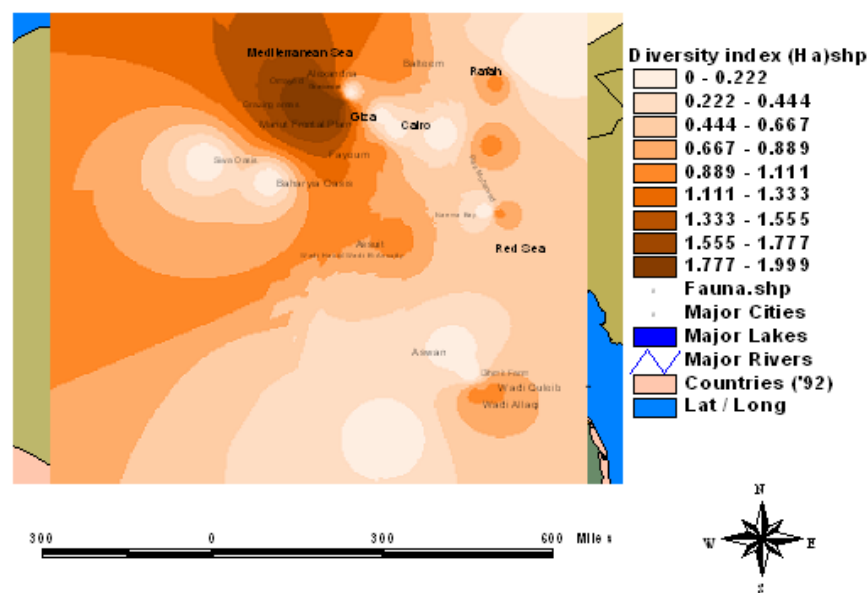


Fig.10: Distribution of diversity index (H') of soil fauna across the different regions in Egypt

4. DISCUSSION

The data on soil fauna populations in the present study belong to a wide range of sites and varying degrees of land use intensity. This variation in geographical-ecological zones in Egypt and in land use

practices impacted on soil fauna density and, in consequence, species diversity and biological functional groups (herbivores, carnivores and detritivores). In this study, the dominant functional group (87% of the population) in the grazing lands of the

western coastal Mediterranean (Omayed and Gharbaniat) is the detritivores (Dictyoptera, Tenebrionidae and Scarabaeidae), making it. Towards the eastern part, detritivores (Dictyoptera and Tenebrionidae), are still the major functional group, but represent only 64%. Similar results are obtained in the dry farming agriculture areas in the same region. Land use practices and patterns therefore have some effect. In the irrigated desert ecosystems, changes in soil fauna groups did not show significant variation except by replacement of some taxa by others, such as introduction of earthworms as major detritivores, through the introduction of Nile water and silt carrying earthworm cocoons. In this respect, earthworms in the irrigated desert agricultural constitute approximately the 32% of the total populations. However, in the earthworms in the rainfed sites constitute approximately 2.2%.

The cluster analysis diagram (i.e., trellis diagrams in Figures 1 and 2), of soil fauna, shows that natural ecosystems are similar to each other and more or less similar to the neighbouring agricultural sites. Earlier studies supported this conclusion (e.g., Ghabbour and Mikhail 1993a, 1993b). Likewise, the fauna of the eastern part of the Mediterranean coastal zone (Balteem and Rafah) are more or less similar. On the other hand, cluster analysis showed dissimilarity between agricultural sites and natural sites in this sector (Figure 1).

In Middle Egypt, in the reclaimed desert areas, which were converted to agricultural land using Nile water, herbivores are again the major component of soil fauna, representing about 20%. Intense agricultural practices in these areas changed the balance of soil fauna functional groups, with use of fertilizers and mono-crop cultivation, allowing the invasion of herbivores with a major shift of other soil fauna functional groups. The exclusion of grazing animals like sheep and goats (macro-herbivores), from these farms allowed an excess of plant primary production, thereby inviting instead micro-herbivores (from soil fauna taxa), to take their place (niche), as the major primary

consumers of living green vegetation. At the same time, it prevented the thriving of detritivores feeding on the dung of the macro-herbivore animals.

The use of the spatial analysis model of GIS using H_a diversity (Figure 10) indicated that higher biodiversity of soil fauna appears in the coastal Mediterranean zone of Egypt, while lower diversity appears southwards and in agricultural areas. These results support the findings of Shakir (1989), Ghabbour and Shakir (1980, 1982a, 1982b, 1982c), Ghabbour *et al.* (1985), and Ghabbour and Mikhail (1993a, 1993 b).

Higher biodiversity in an ecosystem increases its functionality. Every species has its own place (or niche) and apparently, nothing is redundant. In consequence, the existence of a balance between functional groups is to be expected. This will appear in natural ecosystems of long existence and with least human interference, as shown at the Omayed and Gharbaniat sites in the western coastal Mediterranean zone. With increasing human interferences through agricultural practices and more intensive land use, there is a reduction in diversity and an imbalance of functional groups, due to increase of species of one functional group (herbivores) over those of another (detritivores). This will lead to less functionality and it is here that redundancy may be provoked (Shakir 1989, 1990; Naeem *et al.* 1994).

However, we must distinguish between ecosystems in transition and those that have reached stability (a climax or a pre-climax). We must also note that desert ecosystems never reach a true climax because of aridity. They are in fact "stunted" ecosystems whose development into mature ecosystems is prevented, or inhibited, by aridity conditions. With the introduction of irrigation water, this stunting is released and the ecosystem does start on a new development anthropogenic path. As this transitional phase is over, redundancy may disappear as species adjust themselves with time and those that are redundant may

disappear with time, due to a settling down of competitiveness.

On the other hand, the degree of climatic variations such as rainfall temperature and relative humidity variability, can affect the geographic distribution of soil fauna diversity, and with it the balance of functional groups. For example, in the southern region of Egypt, with hyper-aridity conditions, diversity is lowest ($H_a = 0.19$), with a lower percentage of herbivores (3%). Sharing in lowering the diversity in this area is the introduction of irrigation water from Lake Nasser (Figure 7). These findings support those of Mikhail (1993a) who showed that community structure and pattern of distribution of soil fauna populations were affected by ecological changes going on in the area, mainly due to increasing human interferences in land use. He further indicated that ecological factors such as soil texture and the existing vegetation types affect soil fauna diversity, their density, and their species richness.

Diversity of soil fauna can be different at the micro-ecosystem level rather than the regional one. In our study, regional biodiversity showed that the Northwest (NW) region has more diversity than the Southeast (SE) region. This is obviously due to the ecological factors of rainfall (180 mm/yr in the NW against only 0.07 mm/yr in the SE). Different soil types and different vegetation cover are also factors that have their influence, but apparently less than climate. They act within what faunal assemblages will be primarily allowed to exist under a certain prevailing climatic regime, which are then secondarily differentiated according to soil type and vegetative cover.

The degree of intensity of agricultural practices has similar impacts on the diversity of soil fauna populations and their functional groups whether under favorable or unfavorable climatic regimes. Under such conditions, it is likely that a small number of key species have considerable effects on ecosystem functions. The crucial question is

whether ecosystems that are more diverse are more resistant or more resilient when environmental conditions change (Folke *et al.* 1996). Concern about decreasing soil organism biodiversity as the result of human impact pressures has been justified with the good argument that high diversity guarantees a source of new species performing functions as human activity or environmental conditions change (Bengtsson 1998). The conversion to agriculture almost always results in fewer species of both introduced and original biota, with lower genetic variation and representing less functional groups. Nonetheless, the extent of diversity in even so-called monocultures may be underestimated by plot-level assessment of diversity at any point in time (Swift *et al.* 2004). The diversity of organisms involved in nutrient cycling may be substantially reduced under agricultural intensification but there is little evidence of significant effects on decomposition and mineralization processes which has been attributed to a high level of functional redundancy among decomposer fungi, bacteria and micro-regulators, such as nematodes or collembola (Beare *et al.*, 1994, 1997; Giller *et al.*, 1997). Furthermore, soil organism biodiversity ensures a multiplicity of functions under a variety of environmental conditions (Giller 1996). Management and development of ecosystems towards sustainability such as agricultural ecosystems, that we are discussing here, will depend on our understanding of the linkages between key species and functionality groups and their biological and geographical distribution as shown in GIS maps (Figures 7-10), and their functionality in transitional ecosystems.

The degree of effect of land-use impacted on soil fauna changes and their diversity can clearly provide us with:

- A - monitoring and prediction of environmental transformation,
- B - early warning for pest species,
- C - identifying the constraints in decomposition of organic matter and nutrient release and recycling.

Application of all these methods of analysis to interpret the data and to extract the most important information indicates that regional diversity of functional groups of soil fauna in Egypt, could describe habitats and ecosystem health, maturity, and productivity. Further, these methods may be of importance in measuring the intensity of human impact on biological systems and land-use pressures. Finally, this will allow decision makers to understand and develop rational planning theories and techniques, for better and more sustainable land use of both natural and manipulated ecosystems.

5. CONCLUSIONS

It is very important to understand that diversity of soil fauna can be different at the micro-ecosystem level as well as the regional level. The regional biodiversity showed that northwestern region is more diverse than the southeastern region. This may be due to the ecological factors such as the level of rainfall and other climatic factors (i.e. higher rainfall in the northwestern region [180 mm / year] rather than southeastern region [0.07 mm/year], soil texture and vegetation types). Additionally, on the regional level the diversity of soil fauna may be affected by the degree of human interference such as agriculture. For example some groups, such as Carabidae, disappear entirely from desert regions in the southeast of the country. In some hyper-arid sites, the predator/prey ratio reaches unity, when the expected ratio should be 1:10. New species invade deserts when irrigation water is brought to these lands for reclamation. Within a certain number of years, the reclaimed desert land may become so similar to "old" Delta land, that the process may be called "Deltaisation". The process may take from five up to 20 years, depending on intensity of land use. It is not a surprise that agricultural pests, such as the mole-cricket and some Lepidoptera, are attracted to these "new" lands.

Analysis of soil fauna functional groups in different regions of Egypt using GIS showed that in general, herbivores are dominant in the reclaimed desert areas.

Herbivores varied between 2% and 14% of the taxa in the agricultural areas. The detritivores represent approximately between 70% and 90% in agricultural areas. On the other hand, carnivores varied between 1% and 35% of the taxa in the studied regions in Egypt (Figures 7-10). Further, there are variations in functionality groups of soil fauna in the other types of land-use. These Figures show that intensity of two of the three soil fauna functional groups (the herbivorous and the carnivorous) is clearly higher in northern Egypt than in the southern part, but that of the detritivorous group is high in both northern and southern Egypt, probably less affected by higher temperatures and lower relative humidity. However, the diversity remains higher in the northern part (Fig. 10). The high intensity of the detritivorous group in the southern part (apparently indicating higher tolerance to higher temperatures and lower relative humidity), therefore has no or little effect on total soil fauna populations diversity. This supposedly higher tolerance to higher temperatures and lower relative humidity may not be due to special adaptations in all or most detritivorous species, but could be rather due to their lesser need of moving outside the soil and litter layers.

Kreyling *et al.* (2008) found low responsiveness of main ecosystem properties in face of artificial weather manipulations of heavy rainfall and extreme drought for two consecutive years. They showed, however, that the plant-soil system (including soil fauna), can buffer against extreme drought events for a certain period. This rendered the detection of significant interactions between weather events and phytodiversity rather impossible. At the other end of low temperature-low-diversity ecosystems in the Antarctic, Barret *et al.* (2008) found that climate-induced decline of a dominant invertebrate species could contribute to significant changes in carbon (C) cycling, illustrating sensitivity of biota in this ecosystem to small changes in temperature. Thus, the influence of a climate-induced decline in abundance of a dominant species

may have a significant effect on ecosystem functioning in that low-diversity ecosystem.

What makes the situation even more complicated is the fact that average temperatures of Mediterranean coastal cities in Egypt did not witness any appreciable elevation in temperature between 1970 and 2005. On the other hand, inner desert cities witnessed a temperature rise of a full 2° C in the same period (Domroes and El-Tantawy 2005). If this difference will be maintained in the coming decades, one may expect a relative stability of soil fauna populations and the balance of their functional groups in the coastal habitats, contrasted by a greater impoverishment and much disruption in the balance of their functional groups elsewhere.

6. ACKNOWLEDGMENT

The authors wish to acknowledge that the original draft of this paper was supported by and benefited from an Egyptian MAB Young Scientists Award from the Egyptian Ministry of Higher Education and the Egyptian National UNESCO Commission to Miss Gehan Sultan. She collected the previous published data of soil fauna from available references to prepare a comprehensive study on the biodiversity of soil fauna in Egypt.

7. REFERENCES

- Ali, A. M. 1985. Studies on the animal fauna at AUPA. *Assiut University Project Area (AUPA)*, Assiut. 65 pp. (unpublished report)
- Ayyad, M. A., Abde1-Razik, M. and Mehanna, A., 1984. Climatic and vegetational gradients in the Mediterranean desert of Egypt. *Actualites bot* 131:129-143.
- Ayyad, M. A. and Ghabbour, S. I. 1977. Systems Analysis of Mediterranean Desert Ecosystems of Northern Egypt (SAMDENE). *Environmental Conservation* 4:91-101.
- Ayyad, M. A. and Ghabbour, S. I. 1986 a. The Omayed Biosphere Reserve: History and future prospects. *Workshop on Biosphere Reserves in the Mediterranean Region*, UNESCO and French National UNESCO-MAB Committee, Cévennes Biosphere Reserve, Florac, France: 20 p.
- Ayyad, M. A. and Ghabbour, S. I. 1986 b. Hot deserts of Egypt and the Sudan. In : M. Evenari, M., Noy-Meir, I. and Goodall, D.W. (eds), *Ecosystems of the World, Hot Deserts and Arid Shrublands*, Elsevier, Amsterdam, 12B: 149-202.
- Beare, M. H., Coleman, D. C., Jr., D. A. C., Hendrix, P. F. and Odum, E. P., 1994. A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. *Plant Soil* 170: 5-22.
- Beare, M. H., Reddy, M. V., Tian, G. and Srivastava, S. C., 1997. Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota. *Appl. Soil Ecol.* 6:87-108.
- Bengtsson, J. 1998. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. *Appl. Soil Ecol.* 10:191-199.
- Bal, L. (1982) *Zoological ripening of soils*. Agricultural Research Reports, FAO, Rome, vol. 850: 375 pp.
- Barret, J. E., Ross, V. A, Wall, D. H. and Adams, B. J. (2008) Decline in a dominant invertebrate species contributes to altered carbon cycling in a low-diversity soil ecosystem. *Global Change Biol.* 14: 1734-1744.
- Berke, S. K. (2010) Functional Groups of Ecosystem Engineers: A Proposed Classification with Comments on Current Issues. *Integr. Comp. Biol.* (2010) 50 (2): 147-157.
- Briones M. J. L., Garnett M. G. and Ineson Ph. (2010) Soil fauna contribution to the decomposition of recalcitrant organic matter in response to warming. *Geophysical Research Abstracts*. 12:7830.
- Brown G. G., Feller C., Blanchart E., Deleporte P. and Chernyanskii S. S. (2004) With Darwin, earthworms turn

- intelligent and become human friends. *Pedobiologia* 47: 924-933.
- Brussaard L. (1998) Soil fauna, guilds, functional groups and ecosystem processes. *Applied Soil Ecology* 9: 123-135.
- Cancela-da-Fonseca, J. P. 1984. L'outil Statistique en biologie du sol. VIII. Diversité et complexité dans les écosystèmes: réflexions sur leur valeur adaptative. *Rev. Ecol. Biol. Sol.* 21:299-327.
- Cancela-da-Fonseca, J. P. 1991. Ecological diversity and ecological systems complexity: local or global approach. *Rev. Ecol. Biol. Sol* 28:51-66.
- Cancela-da-Fonseca, J. P., Ghabbour, S. I. and Hussein, A. M. 1984. Characterization of soil mesofauna in a xero-Mediterranean ecosystem after a 3-year grazing management. *Ecol. Mediterr.* 10:121-131.
- Darwin C. (1840). On the formation of mould. *Transactions of the Geological Society of London* 5:505-509.
- Darwin C. (1881). *The Formation of Vegetable Mould through the Action of Worms, with Observations on their Habits*. London: John Murray.
- Decaëns Th. (2010) Macroecological patterns in soil communities. *Global Ecol. Biogeogr.* 287-302.
- Decaëns Th., Jiménez J. J., Gioia C., Measey G. J. and Lavelle P. (2006) The values of soil animals for conservation biology. *European J. Soil Biology* 42, Suppl. 1:23-38.
- Deshmukh I. 1986. *Ecology and Tropical Biology*. Blackwell, Palo Alto.
- Domroes M. and El-Tantawy A. (2005) Recent temporal and spatial temperature changes in Egypt. *Int. J. Climatol.* 25: 51-63.
- Eijsackers H. (1982) *Environmental Monitoring and Assessment* 3: 307-316.
- Eisenhauer N. and Schädler M. (2010) Inconsistent impacts of decomposer diversity on the stability of aboveground and belowground ecosystem functions. *Oecologia* 164: 13 pp. [Epub ahead of print]
- El-Shishini H. and Ghabbour S. I. (1988) Environmental site characterization by soil fauna in Egypt and Africa. *Revue de zoologie africaine*, Editions AGAR, Belgium 102: 333-345.
- Escofier B. and Pagès J. 1990. *Analyses Factorielles Simples et Multiples, Objectifs. Methodes et Interpretation*. 2nd edition. Dunod, Paris.
- ESRI 1996. Using ArcView, Geographic Information System (GIS). ArcView GIS. The Geographic Information System for Everyone.
- ESRI 1996. Using the Geographic Information System (GIS). ArcView Spatial Analyst. Advanced Spatial Analysis Using Raster and Vector Data.
- Gaston K. J., Warren P. H. and Hammond P. M. 1992. Predator: non-predator ratios in beetle assemblages. *Oecologia*. 90:417-421.
- Ghabbour S. I. (1968) Methods for the utilization of radio-isotopes in the study of ecosystems. *Rev. Ecol. Biol. Sols* 5: 245-263.
- Ghabbour S. I. (1988) Research on soil fauna at the Department of Natural Resources, Institute of African Research and Studies, Cairo University. *Revue de zoologie africaine*, Editions AGAR, Belgium 102: 396-379.
- Ghabbour, S. I. (1991) Towards a zoosociology of soil fauna. *Rev. Ecol. Biol. Sols* 28: 77-90.
- Ghabbour S. I. and Mikhail W. Z. A. (1988) *Species richness of soil fauna as criteria for priority choices of protected areas. Environmental Studies. Final Report*. Foreign Relations Coordination Unit, Supreme Council of Universities-Institute of African Research and Studies, Cairo University, Cairo. Grant #842091: 65 pp.
- Ghabbour, S. I. 1986. Effect of land use on soil fauna. Final Report IARS/UNESCO Project 210125/5, IARS, Cairo University. Cairo, Egypt, 45 p.

- Ghabbour, S. I. 1988. Species richness of soil fauna as criteria for priority choices of protected areas. Final Report. FRCU grant 84091, Supreme Council of Universities, Cairo.
- Ghabbour, S. I. 1992. Elements for a national biodiversity strategy (Egypt). Paper presented at: Seminar on the National Egyptian Biodiversity Strategy, Egypt. Env. Affairs Agency (National Biodiversity Unit) and UNEP, 9-12 Nov.1992. in, Cairo, Egypt.
- Ghabbour, S. I., Cancela-da-Fonseca, J. B. and Shakir, S. H., 1988. Characterization of soil mesofauna in agro-ecosystems of the Mariut region, Egypt. *Rev. Biomath.* 102:26-40.
- Ghabbour, S. I., Cancela-da-Fonseca, J. P. and Mikhail, W. Z. A., 1984.- The characterization of soil mesofauna at the Omayed biotopes, the Mariut area, Egypt. *Bull. Soc. Bot. France.* 131:329-339.
- Ghabbour, S. I., Cancela-da-Fonseca, J. P., Mikhail, W. Z. A. and Shakir, S. H., 1985. Differentiation of soil mesofauna in desert agriculture of the Mariut region, Egypt. *Biol. Fert. Soils* 1:9-14.
- Ghabbour, S. I. and Mikhail, W. Z. A. 1985. Species Richness of Soil Fauna as Criteria for Priority Choices of Protected Areas. Interim Report. FRCU Grant #842091, Supreme Council of Universities and Institute of African Research and Studies, Cairo University, Cairo, Egypt.
- Ghabbour, S. I. and Mikhail, W. Z. A. 1997. Soil meso-fauna in unstable environments and their population density-biomass relationship: Cases from the Egyptian deserts. *Geobios*, M.S. 21:135-144.
- Ghabbour, S. I. and Mikhail, W. Z. A. 1993 a. Habitat classification using soil fauna. In: M. E. Kassas, (ed.) *Habitat Diversity*. National Biodiversity Unit, Egypt. Environmental Affairs Agency and UNEP, Cairo, Egypt, 203-236.
- Ghabbour, S. I. and Mikhail, W. Z. A. 1993 b. Diversity of soil fauna in Egypt. *Mésogée* 53:21-34.
- Ghabbour, S. I., Mikhail, W. Z. A. and Rizk, M. A., 1977. Ecology of soil fauna of Mediterranean desert ecosystems in Egypt. I.- Summer populations of soil mesofauna associated with major shrubs in the littoral sand dunes. *Rev. Eco. BioL. Sol.* 14:429-459.
- Ghabbour, S. I. and Shakir, S. H. 1980. Ecology of soil fauna of Mediterranean desert ecosystems in Egypt. III. Analysis of *Thymelaea* mesofauna Populations in the Mariut frontal plain. *Rev. Ecol. Biol. Sol* 17:327-352.
- Ghabbour, S. I. and Shakir, S. H. 1982 a. Population parameters of soil mesofauna in agro-ecosystems of the Mariut region, Egypt. I-Under farmed almond. *Rev. Ecol. Biol. Sol.* 19:73-87.
- Ghabbour, S. I. and Shakir, S. H. 1982 b. Population parameters of soil mesofauna in agro-ecosystems of the Mariut region, Egypt.II-Communities under dry-farmed fig (*Ficus carica*). *Rev. Ecol. Biol. Sol.* 19:383-401.
- Ghabbour, S. I. and Shakir, S. H. 1982 c. Seasonal variations in community of soil mesofauna under annual field crops in the Mariut desert of Egypt. *Sci. Rev. Arid Zone Res.* 1:351-377.
- Ghabbour, S. I. and Shakir, S. H., 1983. Some features of important taxa of soil mesofauna in an afro-Mediterranean coastal desert. II. Soil mesofauna in irrigated vineyards. *Cairo Univ. Afri. Stud. Rev.* 12:13-38.
- Ghabbour, S. I. and Shakir, S. H. 1984. Some features of important taxa of soil mesofauna in an afro-Mediterranean coastal desert III. Soil mesofauna under dry-farmed olive. *Cairo Univ. Afri. Stud. Rev.* 14:15-44.
- Giller, K. E., Beare, M. H., Lavelle, P., Izac, A.-M. N. and Swift, M. J., 1997. Agricultural intensification, soil biodiversity and agroecosystem function. *Appl. Soil. Ecol.* 6: 3-16.

- Giller, P. S. 1996. The diversity of soil communities, 'the poor man's tropical rainforest'. *Biodiversity Conservation* 5:135-168.
- Hamilton, W. E. and Dindal, D. L. 1989. Influence of earthworms and leaf litter on edaphic variables in sewage-sludge-treated soil microcosms. *Biol. Fertil. Soils* 7:129-133.
- Hansen, R. A. 2000. Diversity in the decomposing landscape. In: D. C. Coleman and P. F. Hendrix, (eds.) *Invertebrates as webmasters in ecosystems*. CABI Press, Wallingford, U.K., 203-219.
- Hågvar S. (1998) The relevance of the Rio-Convention on biodiversity to conserving the biodiversity of soils. *Applied Soil Ecology* 9 :1-7.
- Howard, P. J. A. 1992. Multivariate analysis. In: J. N. R. Jeffers, (ed.) *Microcomputers in Environmental Biology*. The Parthenon Publ. Gr., Camforth, U.K., 103-223.
- Kardol P., Nicholas Reynolds W., Norby R. J. and Classen A. T. (2011) Climate change effects on soil microarthropod abundance and community structure. *Applied Soil Ecology*. 47: 37-44.
- Kevan, D. K. McE. (1955) *Soil Zoology. Proceedings of the University of Nottingham Second Easter School in Agricultural Science*, Butterworth Scientific Publications, London: xiv + 512 pp.
- Kromp, B. 1990. Carabid beetles (Coleoptera, Carabidae) as bioindicators in biological and conventional farming in Austrian potato fields. *Biol. Fert. Soils* 9:182-187.
- Mikhail, W. Z. A. 1987. Integration of Anima/ Wildlife in Egypt and the Sudan: A Study of Some Groups under Different Rain Regimes with Special Reference to Invertebrates in the Region of Khartoum. Ph.D. Cairo University, 249 p.
- Mikhail, W. Z. A. 1992. Soil fauna under major shrubs in grazed and protected plots at the Omayed Biosphere Reserve. I. Population density. In: J. C. Amiard and J. M. Robert, (eds.) *Actes du Colloque le Littoral, ses Contraintes Environnementales et ses Conflits de Utilisation*, Nantes, France, 1-4 Juillet 1991, 315-318.
- Mikhail, W. Z. A. 1993 a. Effect of soil structure on soil fauna in desert Wadi in Southern Egypt. *J. Arid Environment* 23:321-331.
- Mikhail, W. Z. A. 1993 b. Soil fauna under major shrubs in grazed and protected plots at the Omayed Biosphere Reserve. II. Species area relationships. *Mansoura Univ. J. Environmental Sci.* 10:289-303.
- Mikhail, W. Z. A. 1998. Activity of the epigenic soil mesofauna in northern Sinai, Egypt. *Zoology in the Middle East* 16:111-120.
- Mikhail, W. Z. A. and Sobhy, H. M. 1992 a. Population ecology of soil fauna in an extreme arid environment in SE desert of Egypt. I-Wadi Allaqi area. In XI International Colloquium on Soil Zoology, Jyväskylä, Finland, 23 p. (Typescript).
- Mikhail, W. Z. A. and Sobhy, H. M. 1992 b. Population ecology of soil fauna in an extreme arid environment in SE desert of Egypt. II- Wadi Quleib area. In: XI International Colloquium on Soil Zoology, Jyväskylä, Finland, 21 p. (Typescript).
- Mikhail, W. Z. A. and Sobhy, H. M. 1992 c. Land reclamation and ecological equilibria of potential pests among soil fauna at Dihmit farm, Aswan desert, Egypt. In: A. Kishk (ed.) *First National Conference, the Future of Land Reclamation and Development in Egypt*, Minia, Egypt, 337-357.
- Mountford, M. D. 1961. An index of similarity and its application to classificatory problems. In: P. W. Murphy, (ed.) *Progress in Soil Zoology*. Butterworth, London, UK, 43-50.
- Murphy P. W. (1957) Review: Soil Zoology. *Ecology* 38: 175-176.
- Naeem, S., L.J. Thompson, S. P. Lawler, Lawton, J. H. and Woodfin, R. M., 1994.- Declining biodiversity can alter the

- performance of ecosystems. *Nature* 368:734-737.
- Odum, E. P. (1959) *Fundamentals of Ecology*. Saunders, Philadelphia and London: 546 pp.
- Reinecke A. J., Van Gestel C. A. M., and Reinecke S. A (2004) Using biomarkers of soil organisms to determine the bioavailability of chemicals for risk assessment and management. In: *Soil Zoology for Sustainable Development in the 21st Century. A festschrift in Honour of Prof. Samir I. Ghabbour on the Occasion of His 70th Birthday*, S. H. Shakir Hanna and W. Z. A. Mikhail, eds.: 427-448.
- Roux, M. 1985.- *Algorithmes de Classification*. Masson, Paris.
- Roux, M., 1987.- *Datavision1.2 logiciel d'analyse de donnees*. CEPE/CNRS, Montpellier, France.
- Salmon, S. and Ponge, J. F., 1999. Distribution of *Heteromurus nitidus* (Hexapoda, Collembola) according to soil acidity: interactions with earthworms and predator pressure. *Soil Biology and Biochemistry* 31:31.
- Salmon, S. and Ponge, J.-F. 1999. Distribution of *Heteromurus nitidus* (Hexapoda, Collembola) according to soil acidity: interactions with earthworms and predator pressure. *Soil Biol. Biochem.* 31:1161-1170.
- Santos, S. n. A. P., Cabanas, J. E. and Pereira, J. A., 2000. Abundance and diversity of soil arthropods in olive grove ecosystem (Portugal): Effect of pitfall trap type. *European Journal of Soil Biology* 3:1-7.
- Shakir, S. H. 1989. Structural comparison of soil macro-invertebrate micro-communities in selected global ecosystems with special emphasis to land-use. Ph.D. State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210, USA., 336 p.
- Shakir, S. H. 1990. Structural comparison of soil macro-invertebrate micro-communities in selected global ecosystems with special emphasis to land-use. *Dissertation Abstract International*. 50:3899.
- Shakir, S. H. and Dindal, D. L. 1997. Density and biomass of earthworms in forest and herbaceous microrcosystems in Central New York, North America. *Soil Biology and Biochemistry*. 29:275-285.
- Shakir Hanna S. H. (2004) A vision of the role of soil fauna as biological agents for sustainable development in the 21st century. In: *Soil Zoology for Sustainable Development in the 21st Century. A festschrift in Honour of Prof. Samir I. Ghabbour on the Occasion of His 70th Birthday*, S. H. Shakir Hanna and W. Z. A. Mikhail, eds.: 475-486.
- Shakir Hanna S. H. (2004) A vision of the role of soil fauna as biological agents for sustainable development in the 21st century. In: *Soil Zoology for Sustainable Development in the 21st Century. A festschrift in Honour of Prof. Samir I. Ghabbour on the Occasion of His 70th Birthday*, S. H. Shakir Hanna and W. Z. A. Mikhail, eds.: 475-486.
- Southwood, T. R. E., (1978). *Ecological Methods With Particular Reference to the Study of Insect Populations*., London.
- Systat. 1998.- 8.0. *Statistics*. SPSS Inc, USA.
- Torrey H. B. and Felin F. (1937) Was Aristotle an evolutionist? *The Quarterly Review of Biology*. 12:1-18.
- Tripathi1 G., Deora1 R. and Singh J. (2010) Biological, chemical and biochemical dynamics during litter decomposition at different depths in arable soil. *J. Ecol. and Natural Environment* 2: 038-051.
- Wallwork, J. A. 1970. *Ecology of Soil Animals*. McGraw-Hill, London, NY.
- Wallwork, J. A. 1976. *The Distribution and Diversity of Soil Fauna*. Academic Press., London.
- Whittaker, R. H. 1972. Evolution and measurements of species diversity. *Taxon* 21:213-251.
- Wolters, V. 2001. Biodiversity of soil animals and its function. *Eur. J. Soil Biol.* 37:221-227.

- Xiao Yihua, Tong Fuchun, Luo Xinhua, Zou Bin, Chen Kanghua, Chen Lin, Feng Shaofeng, Hou Huating, and Li Zhanxiong (2010) Functional groups of soil fauna in Yangdongshan Shierdushui Nature Reserve in North Guangdong Province after ice-snow disaster. *J. NE Forestry Univ.*, China: p 7.
- Zedan, M. A., Rizk, M. A. and Mikhail, W. Z. A. 1993. Recovery of soil fauna after insecticide treatment in a cotton field at Etsa, Fayoum. *Afr. Agric. Sci.* . 20:143-151l.