HEAVY METAL ACCUMULATION IN ORIBATID MITE SPECIES (ACARI: ORIBATIDA) IN AGROECOSYSTEMS IN EGYPT. A CASE STUDY

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ABSTRACT: The responses of oribatid communities to heavy metal contamination were studied. Concentration of cadmium, copper, lead and zinc in oribatid species along Ismailia water canal, Egypt was measured. Metal levels observed in both soil and irrigation water was compared with standard values of FAO and established permissible levels reported by different authors. Mean concentration of heavy metals determined in irrigation water were much above the recommended levels. Concentrations of all the metals (mg kg^{-1} dry weight) in the studied agricultural soil were below the permissible level standard. The comparison of mean concentrations of heavy metal in examined soil with that of typical uncontaminated soil in this area revealed that Ismailia water canal using in irrigation of agricultural soil has increased the levels of heavy metals. All studied oribatid species appeared to be accumulator's different amount of heavy metals characterized by the highest bioconcentration factors. The results of the study show that the abundance and structure of the soil oribatid communities in the sampling locations were not influenced by levels of heavy metals in the soil. They also show that the diversity index can be valuable tools for assessing the impact of pollutants on different species of oribatid mites.

KEY WORDS: Oribatid mites, heavy metals, bioindicators, pollution, diversity.

Oribatid mites have successfully invaded almost all compartments of the biosphere. Apart from the diversity of habitats, their excessive adaptation ability is shown by great abundance and species richness. In most habitats, they constitute the largest proportion of microarthropods diversity. Oribatid mites consume mainly living or dead parts of plants or fungi, however there are some predators and scavengers to be mentioned as exceptions (Behan-Pelletier, 1999). As a consequence, they consume various kinds of food, and as such, they participate in numerous ways in the structure of the food web (Lebrun & Van Straalen, 1995).

The reproduction biology and life cycle of oribatid mites can be considered extraordinary among arthropods from several aspects. The slow development, low fecundity and long larval stage of oribatid mites can help indicating long-term disturbances. Their low dispersion ability (Lebrun & Van Straalen, 1995) is also quite important, since these mites can hardly flee from sites affected by some kind of stress. Because of their important role in detrital food webs, there is increasing interest in their reaction to environmental conditions such as heavy metal pollution (Zaitsev & Van Straalen, 2001). Several studies have measured directly the accumulation of pollutants, in most cases heavy metals, in oribatid mites (Ludwig et al., 1992; Roth, 1993; Janssen & Hogervorst, 1993; Siepel, 1995; Heck et al., 1995; Van Straalen et al., 2001; Zaitsev & Van Straalen, 2001; Zaitsev et al., 2001; Skubala & Kafel, 2004; Gulvik, 2007). These studies have shown that oribatid mites easily accumulate environmental pollutants, such as heavy metals, but again there is a clear variation among species according to their diet. For example, copper has been shown to accumulate effectively in oribatid species (Skubala & Kafel, 2004).

Heavy metal pollution of water and agricultural soil is one of the most severe ecological problems on a world scale and also in Egypt. Long-term use of polluted water in irrigation is known to have significant contribution to trace elements such as Cd, Cu, Pb and Zn in surface soil (Sharma et al., 2007). Excessive accumulation of trace elements in water and agricultural soils through drainage water irrigation may not only result in soil contamination but also affect food quality, safety, and has a damaging effect on all aquatic life (Sharma et al., 2007). Up to the present, the hazardous effects of prolonged irrigation by Ismailia Canal water on Acari: Oribatida in the agroecosystem of Ismailia Governorate, Egypt, has never been the target of any study before. This paper investigates the level of Cd, Cu, Pb and Zn in irrigation water, soils, and in oribatid mites from agricultural land Ismailia Governorate, Egypt, which is one of the largest area of mango fruits in Egypt. The aim of the work was to highlight the potential of Oribatid mites as indicators of ecosystem change in response to contamination and establish baseline data for these metals. The concentrations of heavy metals in water and soil were compared with the established safe limit, while the concentrations of heavy metals in oribatid mites were compared with previous studies of different authors. This provides a basis for guiding further activities aimed at preventing exposure of humans through monitoring and control of irrigation water.

MATERIALS AND METHODS

Study Area

The subject of the present investigation is Ismailia Governorate, Egypt, (30° 58′ N and 32° 23′ E and elevation above sea level, 13 m). The area is almost flat and wetland with fertility soil and good climate. It is characterized by aridity with long hot rainless summer, mild winter and low amount of rainfall (50 mm). Ismailia Water Canal is considered the main source for fresh water, as it carries water from the Nile River. It is used in drinking, irrigation and industry (Egyptian Environmental Affairs Agency, 2008).

Sampling

Five study sites were chosen along Ismailia water canal namely, Nefisha (site 1), Abou-Souier (site 2), Kasaseen (site 3), Mahsama (site 4) and Aldaheriya village (site 5). Three random soil samples of topsoil (0 - 20 cm), under mango trees, *Mangifera indica* L. (Family: Anacardiceae) were taken using a corer from March to October 2009. These areas were cultivated and irrigated by Ismailia water canal during such periods. Soil samples were taken from a representative quadrate (5 x 5 m) at each site. Sampling was done monthly (four times), making a total of 12 samples per date. A total of 480 samples were collected. The representatives of oribatida were separated from the soil using the Tullgren method. Mites extracted for heavy metal determinations were preserved in a mixture of water and glycerol with addition of alcohol and kept in a refrigerator to avoid evaporation and development of microflora. Oribatid mites were identified according to Balogh (1972).

Water analysis

Samples has been subjected to various analyses including pH value (using electronic pH meter), Total Soluble Salts (TSS) in mg L^{-1} according to Westerman (1990) by estimation of electric conductivity (EC), using conductivity meter. Total nitrogen, total phosphate and heavy metals were analyzed according to Standard methods for examination of water and wastewater (APHA, 1995).

Soil analysis

To perform chemical analyses, surface layers (0–20 cm) of all examined soil samples were selected. Organic matter content was determined and estimated according to Jackson (1967). Total calcium carbonates and chemical properties were determined according to Page et al., (1982) and Jackson (1967). Heavy metals (Cd, Cu, Pb and Zn) were analyzed by the total adsorbed metals, using atomic spectrophotometer (Thermo-electron, S Series GE 711838).

Test species and analytical methods

For analysis of metal body burden, the species should be quite numerous, larger species and species which occur at all sample sites are preferable and suitable for searching trends of metals accumulation. Four species were chosen for the present study: *Pergalummna flagellate, Scheloribates lavigatus* (Koch)*, Zygoribatula undulata* Berlese*, Zygoribatula tritici* El-Badry & Nasr and *Oppiella nova* (Oudemans). The mite species were pooled and weighted to establish their proper weight (1g), then dried and digested in a mixture of concentrated nitric and perchloric acids (7 : 1 by volume) and diluted in H_2O. Determination of metal concentration was done with using atomic spectrophotometer (Thermo-electron, S Series GE 711838), background correction of deuterium lamp: 164.49. The values of relative standard deviation (RSD) for Cd, Cu, Pb and Zn were 0.9, 1.3, 417 and 0.3 %, respectively.

Data Analyses

The oribatid communities were characterized by the following indices: abundance, species richness and dominance, Shannon index of diversity (*H'*), and equitability (*J*). Differences between the sites were evaluated using One-Way ANOVA; this was followed by a multiple comparison of the means using Duncan's test. The bioconcentration factor (BCF) of heavy metals was calculated according to Skubala and Kafe (2004). To assess the contamination level of heavy metals, mean, minimum, maximum, and standard deviation of water, soil, and oribatid mites were performed using Microsoft Excel.

RESULTS

Water analysis and heavy metal concentration

The pH values in Ismailia water canal ranged between 7.50 and 9.91 in all studied sites along the canal (Table 1). Total phosphate content showed a mean value 4.14 mg L^{-1}, with the highest absolute value 4.86 and the minimum absolute value 3.11 mg L^{-1}. All heavy metals determined in water samples were exceeded the standard levels of irrigation water as described by FAO (Pais & Jones, 1997).

Heavy metal concentration in soil

The texture of soils under investigation is sandy loam according to particle size distributions. Across the studied profiles, total calcium carbonate percentage ranged between 0.18 and 1.34% (Table 2). The soil profiles are alkaline where soil pH values ranged between 7.48 and 8.12. The mean values of total organic matter (TOM) percentage ranged between 0.39 and 0.95%. In addition, the contents of calcium carbonate are considerably low. Heavy metals (Cd, Cu, Pb and Zn) recorded in high concentrations in the soil, which reflect the degree of pollution compared to the concentrations of normal and nonpolluted soils in Egypt (Table 2). Zinc content of the studied soil profiles samples not exceeds the maximum acceptable concentration in soils (300 m kg^{-1}). It is varied from 4.97 to 7.77 m kg^{-1}, in which the highest absolute value for Zn content was recorded in sites 2 and 4, and the lowest one in site 5. Lead content not exceeds the maximum acceptable concentration (100 m kg^{-1}) in which the mean values ranged between 8.50 and 13.50 m kg^{-1}. While the maximum acceptable concentration of cadmium in soils is 5 m kg^{-1}, the cadmium content varied from 0.12 to 0.24 m kg^{-1}. The mean value for copper ranged between 11.39 and 15.59 m kg^{-1} within all investigated sites.

Oribatid mites community

In total, 7746 specimens and 15 species of oribatid mites belonging to 14 genera were found at different sites in the study area. The distribution of oribatid species over sites is shown in Table 3. Site four had the highest total density of oribatid mites in comparison with the others. Here mites reached a density of 3024 individuals, while the lowest density was observed in site 1 (659 individuals). The two-way ANOVA revealed significant differences in oribatid abundance between site 4 and the other sites (p < 0:05). The highest abundance of oribatids was noted in site 4, while the lowest abundance was noted in site 1 (3024 indiv. and 659 indiv., respectively) (Table 3).

Differences in species richness were not so remarkable between sites. The highest number of species was recorded in sites 3 and 5 (15 species). However, species richness at the two sites was only slightly higher than in site 2 (14 species). On the hand, the lowest number of species was recorded in sites 1(10 species) with the highest contamination with heavy metals. Site 4 was characterized by the lowest species diversity (*H'* = 1.925), while the highest value of the Shannon index was the at site 3 (*H'* = 2.524). Results regarding equitability (*J*) among all sites were similar as in Shannon index (Table 3). The most dominant species was *Scheloribates lavigatus* (28.8 %) and *Zygoribatula undulata* (24.11 %) for site four. Meanwhile, *Z. undulata* was the most dominant species in site five. On the other hand, *Oppiella nova* was the most dominant sites one and two (15.36 and 14.44 %, respectively) (Table 3). Some species were not observed at sites 2 and 4; these were: *Cosmochthonius lantus* (Michael), *Ctenacarus araneola* (Grandjean) and *Aphilacarus acarinus* (Berlese). On the other hand, *Papillacarus aciculatus* Kunast was not observed in sites 1 and 2.

Metal accumulation by oribatid species

Data on heavy metal concentrations in various species of oribatid mite are represented in Table 5. For most of the metals, oribatid mites had the low concentrations. Although the concentrations of cadmium in soil and water were low (Table 2 and 3), cadmium concentrations in various species of oribatid mite were detected. The highest concentration was found in *Pergalummna flagellata* (3.73 mg kg^{-1}) in site 1, and the lowest in *Oppiella nova* (0.11 mg kg^{-1}) in site 5. Nevertheless the concentrations of this metal in mites were much higher than in soil and water. Copper (Cu) accumulation seemed to be very different from cadmium. The highest levels of Cu were found in *Pergalummna flagellata* and *Zygoribatula undulata* in site 2 (25.27 and 45.52 mg kg^{-1}, respectively). The lowest concentration was observed in *Oppiella nova* in site 5 (7.7 mg kg^{-1}) (Table 5). Lead (Pb) concentrations were more similar among the species, and data showed that site 2 was the highest concentration of Pb in *Pergalummna flagellata Scheloribates lavigatus* and *Zygoribatula undulata* (Table 5). The highest concentration of zinc (Zn) was observed in site 3 in *Pergalummna flagellata* (83.77 mg kg^{-1}, respectively). However, the differences in zinc concentrations between mite species in the same site were not high. Microphytophagous mites (e.g. *O. nova*) accumulated in general more zinc than other species . This species had height Zn concentrations (feeding both on fungi and dead organic matter). Only in the case of lead and zinc in *Oppiella nova*, the highest concentrations were observed in site 3 (46.29 and 62.1 mg kg^{-1}, respectively). The trends of concentration for heavy metals in different oribatid mite studied were in the order Zn > Pb > Cu > Cd. On the other hand, different pattern was found for oribatid species with each metal separately as following: Cd, mites in the order *Z. undulata,* > *O. nova* > *P. flagellate* > *S lavigatus*, Cu*, Z. undulate* > *P. flagellata* > *O. nova* > *S. lavigatus* ,Pb*, P. flagellata* > *O. nova* > *S. lavigatus* > *Z. undulate,* and Zn, *P. flagellata* >*S. lavigatus* >*Z. undulata* > *O. nova.*

The bioconcentration factors (BCF) of the metals measured in the oribatid mite species in comparison with metals total content in the soil are shown Table 6.

BCF is a parameter used to describe the transfer of trace elements from soil to oribatid body. It is notable that different oribatid mite species have quite different concentration ability for certain metals. The greatest BCF are found for cadmium and lead in all oribatid mites. BCF differs between sites. However, it was impossible to find a general rule for species analysed at all investigated sites. BCF was high with cadmium in all studied sites. Similar trend of lead can be observed (Table 6). The only exception is the cadmium burden in *Oppiella nova* (0.79) in site 5. On the other hand, the highest value for cadmium was 25.92 in *P. flagellate* in site 1. No clear trend about copper. Regarding to zinc, *P. flagellate* are not enriched with metal in all studied sites, with exception for site 3. Concentration of this metal in the body of oribatids was higher to the concentrations in the soil and irrigation water.

DISCUSSION

Water analysis and heavy metal concentration

In spite of the great importance of soils in Ismailia Governorate for agricultural production in Egypt, little information exists about using mites as indicators of soil contaminated by heavy metals. This study was therefore undertaken in soils, water and oribatid mites of this area in order to identify the current levels of heavy metals. Physio-chemical analysis of water in the present study showed that irrigation water contained different amount of heavy metals.

This might be due to a variety of industries discharging their treated and untreated waste water into the Ismailia canal which was the source of water used for irrigation purposes. In comparison with the standard guideline of irrigation water (Pais & Jones, 1997), it was found that the mean concentration of Cd, Cu, Pb and Zn was higher than the recommended permissible level (Table 2).

Heavy metal concentration in soil

The order mean highest concentration of heavy metals (mg kg^{-1} dry soil) in agricultural soils of the study area (Table 3) was Cu > Pb > Zn > Cd. The extent of metals observed in agricultural soil in the present investigation exceeded the permissible levels reported by different authors like Kabata-Pendias and Pendias (1992) (Table 3). The comparison of mean concentrations of heavy metals in soil of the study area with the Egyptian non-polluted soils (Aboulroos et al., 1996) and maximum allowable concentration (MAC) of elements in agricultural soil showed that all of heavy metal concentrations were not exceeded the permissible levels (Table 3). The agricultural soil is contaminated with heavy metals through the repeated use of wastewater from different sources in irrigation as well as application of chemical fertilizers and pesticides. Cd, for example, is found in wastewater and also in phosphatic fertilizers. On many of agricultural soils, with the use of effluent contaminated water in irrigation, heavy doses of phosphate fertilizers have been applied for over 45 years.

Oribatid mite communities

The highest abundance of oribatids was observed in site 4 followed by site 5 (Table3). These sites are characterized by moderate contamination of heavy metals. Species richness was also the highest in the oribatid community in sites 5 , 3 and 2 compared with other studied sites. However, increased abundance of mites in sites 4 and 5 was probably due to increased volume of habitat as a result of accumulation of large amounts of un-decomposed leaf litter. The lowest abundance and number of species were noted in site 1, which is the most contaminated. Trace element and soil properties of site 1 may play a more important role in forming mite community diversity, and many species have disappeared in comparison with other sites. The reduction of the abundance and species richness of oribatid mites in some sites with high heavy metal concentration is not contradictory and well documented in the literature (Bengtsson & Tranvik, 1989; Gackowski et al., 1997).

Accumulation of heavy metals in oribatid species

Recently, metal concentrations were estimated in more than 30 species of mites along a contamination gradient (Zaitsev & Van Straalen, 2001; Skubala & Kafel, 2004). But unfortunately there are no studies on oribatid mites related to the environmental changes such as soil contamination with heavy metals as well as the validity of the water used in irrigation at least in Egypt.

Zinc concentration varied from 14.71 mg kg^{-1} in *Z. undulata* (site 5) to 83.77 mg kg^{-1} in *O. nova* (site 1). The variation in copper content in oribatids was not higher, except in *P. flagellate* and *Z. undulata* in site 1. Only, the variation of cadmium burden was slight in most species (from 0.11 mg kg^{-1} in *O. nova* in site 5 to 3.73 mg kg^{-1} of *P. flagellate* in site 1). If we compare concentrations of cadmium in *P. flagellate* and *O. nova* in the present study with the lethal body concentrations established for *Pergalumna nervosa* and *Oppiella nova* (1.9 and 2.9 µg g^{-1},repectively see Skubala & Kafel, 2004) we can conclude that they are too low to cause any harm for them.

Concentrations of zinc and copper were higher in microphytophagous species (*O. nova*) compared with the panphytophagous (*P. flagellata*) feeding groups (Skubala & Kafel, 2004). The accumulation of zinc could be related to feeding on fungi, which is important part of microphytophage diet. Also, fungi are known as effective heavy metals accumulators (Khan et al., 2000). Heavy metals accumulating in fungi appear to be concentrated in cell walls (Siepel, 1995). Nevertheless, it is difficult to draw some general conclusions on the relationship between feeding type and heavy metal bioaccumulation, because of the lack of precise information on feeding habits of many oribatid species.

The bioconcentration factors increased along the range: Cd > Pb > Cu > Zn for most of the species in almost all sites (Table 6). Zaitsev (1999) found that nine oribatid species were investigated in the surroundings of the metallurgical plant revealed the highest concentration factors for cadmium followed by zinc and copper. The greatest bioaccumulation factors were found for cadmium in all oribatid species, for example it was (25.92) in *P. flagellate*. Skubala & Kafel (2004) noted the highest concentration factors in *Pergalumna nervosa* for cadmium (0.04). A high concentration factor for copper may be expected in species, which use hemocyanin as an oxygen carrier, such as snails, isopods and some arachnids (Janssen & Hogervorst, 1993). As oribatids do not possess hemocyanin (Krantz, 1978), high copper concentrations may indicate the presence of other substances, which are capable of accumulating copper or crucial role of this element in the metabolism of oribatids. The low concentration factors of heavy metals may be explained by the ability of species to prevent high internal metal concentration, either by low uptake through the gut wall or by rapidly excreting (Janssen & Hogervorst, 1993). In conclusion, we can use oribatid mites as bioindicators to assess the environmental changes, particularly in the soil such as heavy metal pollution; this is due to the low fecundity of most oribatids and their poor power of dispersal.

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