Contribution of earthworms to enhance fertility in selected orchards of Faisalabad district

Fatima Jalal1, *, Junaid Iqbal Qureshi2, Shazia Anwer Bokhari3, Asma Haque4, Zafar Mahmood Khalid5, Shahnaz Akhter Rana2

1Dept. Zoology, Wildlife and Fisheries, Faculty: Science and Technology, GC. University, Faisalabad Pakistan
2Dept. Zoology and Fisheries, University of Agriculture (UAF) Faisalabad, Pakistan
3Department of Applied Chemistry and Biochemistry, GCUF, Faisalabad-38000, Pakistan
4Dept. Bioinformatics, Faculty: Science and Technology, GC. University, Faisalabad Pakistan
5Department of Bioinformatics and Biotechnology, Faculty of Basic and Applied Sciences, IIU, Islamabad, Pakistan

Key words: Earthworms, nutrients, orchards, Pheretima, climate.

http://dx.doi.org/10.12692/ijb/5.9.75-84 Article published on November 10, 2014

Abstract

The influence of earthworm’s abundance on the soil texture, physiology and available nutrients in natural conditions were investigated in the four orchards, Orange (Citrus reticulata), Guava (Psidium guajava), Mango (Mangifera indica) and Berri (Zizyphus mauritiana). Samplings were done every month with five replicates, throughout the years in session (1997-1998). Up to 18 species belonging to 10 genera were harboured from the selected sites. Overall, about 87.57 % (n=458) of earthworms were belonging to genus Pheretima while the rest of species are poorly present. Climatic factors affected the diversity and abundance of the earthworms (p = 0.01, p = 0.05). The number earthworms were abundant near tree trunks where different species of herbs and shrubs were present which provided shelter against adverse environmental factors. Genus Pheretima had fairly found throughout session. A fair number of casts were found in the Berri orchards and least in the guava orchards. The casts and burrows were frequently present near the tree stem within the intermingled roots. The shape and size of the casts and the burrows depends on the species as well as the age of the earthworms and having a linear correlation between the soil fertility and abundance of earthworms (p = 0.01, p = 0.05). This correlation indicated that the presence of earthworms in orchards increase soil fertility and having the ultimate influence to enhance the productivity of the orchards.

*Corresponding Author: Fatima Jalal fatima_jalal@hotmail.com
Introduction

Earthworms are an eminent component of soil fauna in the global soils and are useful indicators of soil health and quality (Edwards, 2004). Pakistan is an agricultural fertile land, and extensive agricultural practices decrease the soil fertility by decreasing soil porosity (Arshad and Coen, 1992) as a result increasing the compactness (Sillon et al., 2003; Lipiec et al., 2006; Blavet et al., 2009) as compared to the orchards where tree trunks provide shelter for the earthworms. A large amount of water transported through burrows (Lamande et al., 2003) and the soil animals increase soil porosity through borrowing activities (Lavelle et al., 2001) which is the consequent source of oxygen supply in the underground soil. Endogeic earthworms play an essential role by accumulation of casts below the soil surface modified the soil matrix with the formation of granular aggregates (Jongmans, 2001). The casts’ ability is to neutralize soil by buffering acid and basic conditions and earthworm tunnels create fertile channels for the growth of plant roots.

Fresh casts are easily dissolved in water but with the passage of time they become dry and more water-stable (Shipitalo, 1988). The climatic factors such as rainfall, raindrop impacts and wet-dry cycles, cattle trampling (Decaens, 2000) and the activities of small dwellers invertebrates, primarily disrupt the above ground casts in natural ecosystem. Therefore, the life span of the below ground casts, are suggested to be longer (Mariani et al., 2007; Lukkari et al., 2006) than those of above grounds. Subsurface casts create a “mammilated vughs” porosity which changes the meso and macroporosity of the soil (VandenBygaart et al., 2000). In addition, their casts and porosity enhance the biogenic soil structure (Pulleman et al., 2003). Some studies on the subsurface casts and their dynamics have been reported (Mcinerney and Bolger, 2000; Feng et al., 2001 and Mariani et al., 2007). No doubt the abundance of earthworms and their positive activities (cast, burrows and biodegradation) in the soil increase the productivity of the orchards. In the previous studies, the cast stabilization mechanisms with the development of fungal hyphae and the production of bacterial polysaccharides/ the arrangement of primary particles were investigated (Marinissen and Dexter, 1990; Schrader and Zhang, 1997; Zhang and Schrader, 1993). A few studies were available on soil fertility and ecology with respect to earthworms in orchards (Jongmans et al., 2001; Schrader, and Zhang, 1997).

The main objective of the present study was to find out the relationship between the soil fertility and the earthworm populations that were inhabited near the tree trunk as well as the climatic influence in the earthworm’s population, and casts formation, which has the ultimate effect on soil geo-physiology of the horticulture experimental orchards. The increase in casts formation and burrows ultimately has an impact on soil physico-chemical properties in order to increase the soil fertility in undisturbed orchards. For the reason orchards were selected in order to investigate the influence of earthworm on the soil and climatic effect on earthworms.

Materials and methods

Site selection and physical factors

For the analysis of earthworm’s effect on soil morphology in the form of burrows and casts, the research area comprised of four orchards viz Orange (Citrus reticulata), Guava (Psidium guajava), Mango (Mangifera indica) and Berri (Zizyphus mauritiana).situated at horticulture experimental orchards (Square No. 9) of the University of Agriculture, Faisalabad, Pakistan (31° 26’ N, 73° 06’ E and at an altitude of 184.4 m above the sea level.). The hottest months are May, June and July, while December, January and February are the coldest months. Two rivers, the Ravi flows on the Eastern, while the Chenab on the Western boundary of the district. The field observation and collection of earthworms was carried out at interval of one month in fully randomized field experiment. The orchards had plain surface topography with clay loam soil texture (Clay = 60.5 %, Silt = 22.5 % and Sand = 17 %). The average rainfall ranged from 280.7 to 800.80 mm and the relative humidity was ranging from 6.7 to
8.0 and 32.2 to 30.9 at 00 UTC and 12 UTC respectively, per year. Wind speed (knots) average 0.3 and 1.2 at 00 UTC and 12 UTC, respectively annually. The annual average maximum and minimum temperatures were 24.0 and 12.5 °C. The earthworm abundance was high close to the tree trunks as compared to the open; regularly tillage areas of the orchards sampled as control/ disturbed areas.

Methods
Four study orchards [orange (n = 500), guava (n = 422), mango (n = 336) and berri (n = 82)] were selected and five samples from each were collected randomly by throwing a quadrate of 12"X 12". Standard field procedures used in soil research and total number and diameter of burrows were measured. Sample was taken from the randomly selected tree trunk A total area of 432 sq. inches was dug divided in to three consecutive of one foot each (12" X 12") up to three ft depth as a third layer. The number of burrows was changed from the above ground level to sub- and below ground level. The change in burrows diameter and length consequently change in texture of the selected soil. Within orchards variations were also observed. Data on temperature, rainfall, wetness and humidity was collected from Meteorological Department, University of Agriculture, Faisalabad, Pakistan. Soil temperature of each sample was also taken round the orchards.

Casts collection
All the casts present on the surface inside the quadrate were collected and air dried for further analysis to know the compactness of the casts. Fresh casts were collected and used as such at spot of analysis for research. A simple method explored as the 10 ml tap water added in 10 g casts in 100 ml conical flasks with gentle shaking and the dissolving time was noted. For this purpose, the earthworms were rear in the laboratory. A hew was used to collect the soil sample (without casts) from randomly selected position within the quadrate for control.

Earthworm collection
A steel quadrate of 12’ X 12’ was randomly located by throwing at 05 different positions within an area of selected tree trunk in the selected orchard. Simple hand sorting technique was employed to procure earthworms (Pelosi et al., 2009). Each specimen of earthworm was given a number and was labeled with site, locality and date of collection. Each specimen was washed with tap water and then anaesthetized in 5.0 % ethyl-alcohol for one to two hours. Each specimen was straightened in a Petri-dish containing 10.0 % formalin and kept as such in 24 hours in order to hardened it. Permanent storage was done in 5.0 % formalin.

Morphological characteristics (Bhatti, 1962; Sims and Gerard, 1985) were recorded for the identification of various species. These are as before and after the preservation, the colour of the specimen as well as the colour of its clitellum was noted. Setal arrangement, position of clitellum, position of dorsal pores, male and female pores, genital papillae, genital pores, spermathical pores, no. of spermathical pores, annulation on the segments, shape of prostomium, peristomium, total no. of segments, and total length of each specimen etc. were recorded.

Results
Table 3 shows the soil physiochemical properties of the 0 – 12 inches top layer in experimental orchards. The soil had an average pH (8.02), overall average OM (1.62 %), average phosphorous and potassium (9.23 ppm, 165.64 ppm) respectively. The soil pH of all orchards was alkaline in nature. It was observed that OM showed high 2.47 % in Guava and steadily decreased in the other orchards, least in orange and mango (1.03, 1.07). The concentration of phosphorous was high in Berri orchards and least in Gauva. The concentration of potassium was high in Berri orchards (189.37 ppm) and least in Mango (142.59 ppm), respectively. The number of earthworms was high in the Berri followed by orange and least in guava orchards.

Five hundred twenty three earthworms were collected from the four orchards. About eighteen species belonging to ten genera were found (Tables 1 and 2)
Pheretima (n = 458), Aporrectodea (19, 3.36 %), Eutypheous (1, 0.19 %), Allolobophora (1, 0.01 %), Dendrobaena (5, 0.96 %), Eudrilus (9, 0.17 %), Ramiella (14, 2.68 %), Microscolex (6, 1.15 %), Octochaetus (05, 0.96 %) and Diccogaster (5, 0.96 %) were identified on morphological characteristics bases. A fair number of Pheretima posthuma (n = 366, 69.98 %), P. hawayana (n = 43, 8.22 %) and P. houleti (n = 27, 5.16 %) were recorded. The least number of harboured were P. morrisi (n = 18, 3.44 %), R. bishambari (n = 14, 2.68 %), E. eugeniae (n = 09, 1.72 %), A. caliginosa (n = 08, 1.53 %), A. rosea (n = 07, 1.33 %), A. phosphoreus (n = 06, 1.15 %), D. pygmaea, O. beatrix and D. modilianii, A. limicola (03), P. elongate (n = 02, 0.38 %) and P. suctoria, A. longa, E. waltoni, A. chlorotica (n = 01, 0.20 %), respectively.

Table 1. Distribution of the earthworm species in the selected orchards.

<table>
<thead>
<tr>
<th>Earthworm species</th>
<th>Orange</th>
<th>Gauva</th>
<th>Mango</th>
<th>Berri</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pheretima posthuma</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Pheretima hawayana</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Pheretima houleti</td>
<td>+</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Pheretima morrisi</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Pheretima suctoria</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Pheretima elongate</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Aporrectodea limicola</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Aporrectodea collignosa</td>
<td>-</td>
<td>++</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Aporrectodea longa</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aporrectodea rosea</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Eutypheous woltomi</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Allolobophora chlorotica</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Dendrobaena pygmaea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Eudrilus eugenia</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Ramiella bishambari</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Microscolex phosphorous</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Octochaetus beatrix</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Dichogaster modigliani</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

- = Absent, ++ = High density population (≥ 6), + = Low density population (6≥).

Beri and mango were diversified with 10 species belonging to 05 genera, respectively, followed by orange (08 species and 04 genera) and guava (07 belonging to 06 genera). In Beri orchards, a total of 301 earthworms were captured, of which 46.27 % (n = 242) were P. posthuma and it did not occur in the samples of February, March, April, only one specimen was harboured in the sample of January. Mango orchards were 7.84 % (n = 41) of P. posthuma out of 79 earthworms, were absent in January to February. Again P. posthuma was abundant 13.38 % (n = 70) in orange orchards but P. hawayana were high in number 2.48 % (n= 13) and followed by P. posthuma 2.42 % (n = 12). Moreover the diversity abundance, richness, evenness and dominance of the earthworm species through Shannon and Weaver index were confirmed (Tables. 1 and 2).

A total area of 144 sq. inches of soil surface contained 127 samples (3.97±0.99g/5) of wet/dry casts and calculated total number of burrows 984 (30.75±4.11). The wet casts did not make aggregate when dissolved in water observed after one hour, while dry casts aggregate depended upon the length of dryness and the climatic conditions. The length of burrows, at the edge of the fields along the water channels were very difficult to measure because of saturation of burrows and casts during the experimental period. In the sugarcane field, between the edge and center, the length of burrows were ranges from 3-53 inches, within the selected quadrate (25.33±2.37”) and in the center the orchards away from tree trunk were present but in low quantity (10.78”±4.11”). In the Beri orchards, their calculated range was 4”-50” (10.97”±7.22”). In the orange orchards, their range
was 3"-53" (12.97"±7.72") and in mango orchards, their range was 2"-49" (14.49"±7.92"). The results indicated that the orchards to orchards variations in the burrowing length were present which were ultimately indicated the earthworm’s diversity and abundance of the species in the selected orchards. 

Tables 3 & 4 revealed that the burrows and the casts were varied which might be due the species differences and stage of the life of earthworms. In case of casts compactness analysis, the fresh casts were easily dissolved in tap water while the dry casts took time to dissolve and the control (sample without casts) also required a time to dissolve, but the length of required time depended on the dryness as well the compactness of the casts and soil.

### Table 2. Diversity, abundance and the dominance of the earthworm species in the selected orchards.

<table>
<thead>
<tr>
<th>Orchards</th>
<th>Species Richness</th>
<th>Species Abundance</th>
<th>Diversity</th>
<th>Max. Diversity</th>
<th>Evenness</th>
<th>Dominance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berri</td>
<td>10</td>
<td>301</td>
<td>0.8058</td>
<td>2.3026</td>
<td>0.3499</td>
<td>0.6501</td>
</tr>
<tr>
<td>Orange</td>
<td>08</td>
<td>97</td>
<td>1.1867</td>
<td>2.079</td>
<td>0.5708</td>
<td>0.4292</td>
</tr>
<tr>
<td>Mango</td>
<td>10</td>
<td>79</td>
<td>1.5525</td>
<td>2.3026</td>
<td>0.6742</td>
<td>0.3258</td>
</tr>
<tr>
<td>Gauva</td>
<td>07</td>
<td>46</td>
<td>1.7516</td>
<td>1.9449</td>
<td>0.9006</td>
<td>0.0999</td>
</tr>
</tbody>
</table>

Tables 4 indicated diameter of the earthworms and the diameter of casts of the abundant genus *Pheretima*. There is a significant difference between orchards to orchards. The results pointed that there is a significant increase water holding capacity near the tree trunks. Although along the water channels one meter zone were saturated with earthworm burrows even the elevated edges showed abundant of burrows with excavated casts. Earthworm burrows increase the rain water holding capacity by filling air spaces of the burrows with rain water. The water holding capacity of a field was also depend on the soil structure, type and the underground fauna.

### Table 3. Soil characteristics and diameter of earthworm burrows underground casts of the selected orchards.

<table>
<thead>
<tr>
<th>Orchards</th>
<th>pH (±SD)</th>
<th>OM (%) (±SD)</th>
<th>P (ppm) (±SD)</th>
<th>K (ppm) (±SD)</th>
<th>Underground casts (Diameter: mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berri</td>
<td>8.05 ± 0.01</td>
<td>1.92 ± 0.25</td>
<td>11.49 ± 0.26</td>
<td>189.37±15.48</td>
<td>5.22 (range 2.5 to 6.0)</td>
</tr>
<tr>
<td>Orange</td>
<td>7.99 ± 0.35</td>
<td>1.03 ± 0.17</td>
<td>10.48 ± 0.38</td>
<td>160.8 ± 15.9</td>
<td>4.98 (range 2.5 to 7.5)</td>
</tr>
<tr>
<td>Mango</td>
<td>8.03 ± 0.02</td>
<td>1.07 ± 0.14</td>
<td>10.68 ± 0.15</td>
<td>142.59 ± 18.10</td>
<td>4.2 (range 3.4 to 8.0)</td>
</tr>
<tr>
<td>Gauva</td>
<td>8.01 ± 0.02</td>
<td>2.47 ± 0.68</td>
<td>4.39 ± 0.69</td>
<td>169.8 ± 13.53</td>
<td>5.11 (range 2.5 to 7.4)</td>
</tr>
</tbody>
</table>

### Discussion

The physicochemical properties of soil in the sugarcane and maize with nearly neutral pH and more than 1% organic matter (OM), are best suitable for productivity and earthworms abundance in contrast to acidic pH (Nakamura, 1998). OM and the quantity of water are the key limiting factors that are sufficient near the channels (Aina, 1984). Therefore, the presence of different species earthworms with different niches is obvious, according the water moisture availability. In case of OM, the litter was more important than OM and different species preferred different decomposing stage of it as different species in the same habitat had their own niche (Judas, 1992). The results of investigations indicated that a period of several years was needed for settlements of earthworms in cropland due to the disturbing factors, tillng, harvesting, fertilization and use of pesticides, even under favourable conditions, in contrast a co relationship between total OM and abundance of earthworms (Blancart et al., 2004; Nakamura et al., 2003; Rehman et al., 2000; Whalen, 2004; Rossi et al., 2006).

In the present study, eighteen species (Table 1) have been reported on the bases of morphological
characteristics. Monthly samples showed that *P. posthuma* was the most abundant species throughout the years except in the months of February. This gap was filled two species, *Aporrectodea caliginosa* and *Eutypheous woltoni* as earthworms activity in the tropics was limited to certain season (Gates, 1961). Most of the species were absent in the cold and dry months of winter (December, January and February) and hot months of summer (May and June) (Pelosi *et al.*, 2009). Therefore in this study, the harsh condition of winter and summer seasons seems to be limiting factors for various earthworm species. Only a few specimens of *P. posthuma* and its close associate *P. hawayana* were found to penetrate to two feet deep in the soil in the winter along *R. Bishambari* and *D. pygmaea*.

### Table 4. Casts diameter of *Pheretima* species (n=50) harbor from the orchards.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Adults (mm)</th>
<th>adult/immature (mm)</th>
<th>Immature (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>3.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Maximum</td>
<td>11.6</td>
<td>8.25</td>
<td>7.7</td>
</tr>
<tr>
<td>Average</td>
<td>10.5</td>
<td>7.27</td>
<td>5.9</td>
</tr>
</tbody>
</table>

The number of species in a given earthworm community which is the simplest measure of species diversity, was ranging from 1-18 species. The Shannon Diversity Index indicated that the submission of the four selected orchards were highly diversified (H= 81.85) as compared to the selectively selected orchards. The comparison between the orchards indicated Berri orchards is highly diversified (38.75) leading to Mango and Orange orchards (26.4, 24.93), except Guava Orchards (15.61). Most earthworm communities contain three to six species indicating the influence of the characteristics of soil, climatic conditions, organic resources of the locality and the history of land use as well as soil disturbance etc. (Edwards and Bohlen, 1996; Whalen *et al*., 1998; Pelosi *et al*., 2009). Therefore, proper wetness and optimum temperature (25 – 35 °C) conditions was favourable factors to enhance the population size of earthworms.

Mostly, species were present near the water channels under the shadow of tall trees as inside the fields where adverse environmental factors, crop rotation, ploughing, limited and are suitable for the survival of the earthworms (Lagerlof *et al*., 2002), in accordance that earthworms were most abundant in non-arable and undisturbed parts of the fields than that of ploughed ones (Ivask *et al*., 2007; Smith *et al*., 2008). This is might be the one main reason for the absence of the earthworms in the center of the orchards, while endogeic earthworms (*Aporrectodea caliginosa, A. rosea, A. chlorotica*) might be dominant in the center of fields in order to resist field practices (Smith *et al*., 2008). The second main reason, small size species (*Ramiella bishambari, Dendrobaena pygmaea* etc.) were mostly present the center of the fields in the cold and dry months of November through February as fields permits (ploughing/ field practices) let not adversely damaged (Lagerlof *et al*., 2002) irrespective to fields provided all the resources necessary for the survival of the species.

A strong linear correlation existed between climatic factors, number of casts, number of burrows and earthworms population. Rainfall, temperature and wetness, having profound linear correlation with the increase of earthworm (p = 0.01 as well p = 0.05), although the relative humidity having inverse linear correlation. Rainfall significantly influenced the earthworm population (p = 0.05) which is indicated in the months of April and May. The primary production and stability plays the key role in agroecosystem maintenance and earthworms played an indispensable role in mediating some biophysical processes for the primary production in the paddy fields (Changuo *et al*., 2006). It is also prove in some agroecosystem, earthworms play vital role in the growth of plants under favourable environmental conditions (Eriksen-Hamel and Whalen, 2007).

The fresh casts (8 h, 12, 24, 48, 72 h) sample had no significant influence on aggregate stability which is
comparable to the previous work (Fonte et al., 2007) while the dry casts made aggregate to some extent and surface casts remained as such for months in the undisturbed areas (control) i.e., surface casts of Martiodrilus sp. remain in the soil surface for months (Decaens, 2000). Moreover, the earthworm’s casts having more fine textured material (Jongmans et al., 2003) due to the combine action of the pH, gut and microfauna present in the gut and increase the gut contents. This fine structure is due to the grinding action of gut which leads to the partial dissolution of clay minerals ultimately earthworm gut allows for the mixing of clay minerals and OM after lubrication with gut mucus to make microaggregates (Oyedele et al., 2006).

All the above data indicated that the earthworm significantly effected on soil physiology and topography which was a profound step to increase soil fertility in the cropping systems. In the present study, four crop fields and climatic factors were influenced earthworm population significantly (p=0.01, p=0.05). The species population was high in the months of April and May, which might be due to favourable climatic changes such as optimum temperature, rainfall and soil wetness, and enough OM providing the favorable conditions for the maintain of earthworm populations in the orchards soils in these months, and the environmental factors responsible to increase the populations of the earthworms (Chang and Chen, 2004, 2005; 2005; Chan and Barchia, 2007).

Conclusion
This study is the first survey of the selected crops with respect to the earthworms (epigiec and endogeic) in relation to abiotic factors in Pakistan. Earthworm population abundance proved to be better and beneficial for increasing the soil fertility, its topography and ultimately, sustainability of the cropping system. P. posthuma and P. hawayana were the species found throughout the study period indicating these could survive with the changing environments.

References


http://dx.doi.org/10.1016/j.agee.2004.01.031

http://dx.doi.org/10.1016/j.still.2009.04.010

http://dx.doi.org/10.1016/j.still.2006.07.006


Chang CH, Chen JH. 2005a. Three new species of octothete pheretimoid earthworms from Taiwan, with discussion on the biogeography of related species. Journal of Natural History 39(18), 1469–82.
http://dx.doi.org/10.1080/00222930400004586


http://dx.doi.org/10.1016/j.agee.2006.11.004

http://dx.doi.org/10.1078/0031-4056-00064

http://dx.doi.org/10.1016/j.soilbio.2006.11.011


http://dx.doi.org/10.1016/S0929-1393(03)00072-6

http://dx.doi.org/10.1007/s003740000318

http://dx.doi.org/10.1016/0038-0717(92)90126-I

http://dx.doi.org/10.1016/S0167-8809(01)00321-8

http://dx.doi.org/10.1016/S0341-8162(03)00114-0

http://dx.doi.org/10.1016/S0929-1393(02)00043-4

infiltration as influenced by tillage methods. Soil and Tillage Research 89, 210 – 220.  
http://dx.doi.org/10.1016/j.still.2005.07.012

http://dx.doi.org/10.1016/j.soilbio.2005.05.015

http://dx.doi.org/10.1016/j.soilbio.2006.09.023

http://dx.doi.org/10.1007/BF00335801

http://dx.doi.org/10.1016/S0038-0717(00)00097-3


http://dx.doi.org/10.1016/j.ecoleng.2006.05.002

http://dx.doi.org/10.1016/j.ejsoilbi.2008.09.013

http://dx.doi.org/10.1111/j.14752743.2003.tb00297.x


http://dx.doi.org/10.1016/S0038-0717(96)00103-4

http://dx.doi.org/10.2136/sssaj1988.03615995005200030030x

http://dx.doi.org/10.1016/S0016-7061(03)00092-2


Smith RG, Meswiney CP, Grandy AS,


