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Ecology and Role of Earthworms in Productivity of Arid Soils of Uzbekistan

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ABSTRACT

Earthworms are key components of terrestrial ecosystems, however, little is known about their ecology, distribution, and taxonomy in arid saline soils of Uzbekistan. This report summarizes the main issues about the ecology of earthworms and their impact on soil properties and plant productivity in saline arid soils. A total of 21 earthworm species belonging to seven different families, *viz.*, *Allolobophora*, *Aporrectodea*, *Eisenia*, *Eisenilla*, *Dendrobaena*, *Dendrodrilus* and *Octolasion* were identified, of which the species *Allolobophora taschkentensis*, *A. ferganae*, *A. kaznakovi* and *Aporrectodea roseus* are endemic for Uzbekistan. The species of *Aporrectodea trapezoides* and *Aporrectodea caliginosa* dominate the earthworm fauna in arid saline soils of Uzbekistan. The diversity and number of earthworms are decreasing under cotton cultivation and increase under lucerne. Furthermore, the application of animal manure and crop rotation increased earthworm density and biomass.

Keywords: arid soils, crop productivity, earthworm diversity, fertilizers, invertebrates
Abbreviations: CEC, cation exchange capacity; **K**, potassium; **N**, nitrogen; **P**, phosphorus

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INTRODUCTION

Earthworms play a critical role in soils and constitute a major component of the biota in many terrestrial ecosystems, usually dominating the biomass of soil invertebrates (Edwards and Bohlen 1996). They function as ecosystem engineers by structuring the physico-chemical environment for the soil community in non-acidic soils (Scheu and Setala 2002; Adigun *et al.* 2008). Earthworms can efficiently consume all types of organic residues, or waste materials including cropping residues, industrial and other organic waste such as *m*unicipal *solid* waste. Earthworm activity promotes and accelerates the decomposition of plant litter (Beare *et al.* 1997; Bonkowski and Shaefer 1997), increases rates of nutrient transformation and plant nutrient uptake, improves the aggregation and porosity of soil, thus enhancing water infiltration and solute transport (Lavelle *et al.* 1998; Bohlen 2002; Ouédraogo *et al.* 2005). About 3,600 species of earthworms have been identified from around the globe (Reynolds 1994). Soil climate determines the time periods for earthworm activity. Within a habitat type, variations in soil climatic factors occur (because of slope, aspect, soil particle size distribution, and drainage characteristics), that result in variation in earthworm activity period and earthworm abundance (James 2000).

In Uzbekistan, studies of the ecology of earthworms are scarce, only very few reports are available from Uzbekistan's arable lands (Valiakhmedov and Perel 1961; Rakhmatullaev 2002; Dadaev *et al.* 2004). These studies mainly deal with the influence of chemical and organic fertilizers on the population dynamics of earthworms and their role in plant productivity.

THE POPULATION AND DIVERSITY OF EARTHWORMS IN SOILS OF UZBEKISTAN

Indiscriminate flood irrigation with poor drainage facilities, deep ploughing of marginal and naturally saline soils, overexploitation of groundwater, recycling of drainage outflows for irrigation, and mono-cropping of high water consumptive crops (e.g. cotton) are the major factors accelerating secondary soil salinization in the Central Asian region of Uzbekistan. In 1990, about 48% of the total irrigated lands were suffering from soil salinity, by 2000, salinity increased to 64% of the total irrigated lands (Qushimov *et al.* 2007).

Several studies have reported that secondary salinity affects soil biological properties. The establishment of earthworm populations in an ecosystem depends on physical and organic properties of soils, on their reproductive potential and the ability to disperse (Edwards and Lofty 1977). The abundance of earthworms can also be affected by various soil chemical properties (Edwards and Bohlen 1996). Thus, Klok *et al.* (2007) reported that the soil acidity significantly affected the population density of epigeic earthworm's spe-

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Table 1 The distribution of earthworms in Uzbekistan soils under various plants. [a]

Plant	Number of earthworms (1 м^2)	Number of earthworms (ha^{-1})
Cotton	11-18	11.000-18.000
Apple	215-250	215.000-250.000
Cucumber	14-30	140.000-30.000
Lucerne	170-230	170.000-230.000

[a] Data from Rakhmatullaev and Mavlanov (1999)

cies in temperate soils under abundant grasslands, also the distribution of earthworms was dependent on physicochemical characteristics of the soil (Tripathi and Bhardwaj 2004). Furthermore, it has been reported that the changes in land use pattern are directly affecting the composition and population structure of earthworm species in different agro-climatic regions (Blanchart and Julka 1997; Bhadauria *et al.* 2000).

The abundance of earthworms especially in arid saline soils varies with cropping of different plant species, whereas their number increased under apple orchards and lucerne in contrast to cotton and cucumber (**Table 1**). It is known that lucerne increases soil productivity due to its capacity to fix nitrogen (N), thus to use of lucerne in a crop rotation may increase the number of earthworms. Karmegam and Daniel (2007) reported that the percentage contribution of N to earthworm population was high. The turnover of N through earthworm tissues can be up to 150 kg N ha^{-1} yr^{-1} (Lee 1985). Earthworm casts contain elevated amounts of inorganic N relative to the surrounding soil. As a consequence, earthworms can greatly enhance the mineralization of N and can stimulate other N transformations such as denitrification (Elliot *et al.* 1990). Lack of organic matter is generally a significant limiting factor for earthworm activity. The fact that most agricultural soils are depleted of readily available organic matter most likely accounts for the lower abundance of earthworms in agricultural land, or recently abandoned cropland (James 2000). In a study of Valiakhmedov and Perel (1961), the number of earthworms under cotton was low, but after the first and second rotation year with lucerne their number slowly increased, which indicates an increase of soil organic matter availability (**Table 2**).

Under continuous cotton cultivation, the diversity and number of earthworms decrease most likely because of intense application of chemical fertilizers and pesticides over many years. These treatments were found to negatively effect the number of earthworms (Rakhmatullaev and Mavlanov 2001). Thus it is important to consider the application of organic fertilizers and to reduce agrochemicals under cotton cultivation in order to increase the earthworm population. The diversity and distribution of earthworms in Uzbekistan were reported in studies of Isakova and Kabilov (1975), Mandrugin and Akhmerov (1994), Rakhmatullaev (2002) and Dadaev *et al.* (2004). There are 21 earthworm species distributed in Uzbekistan soils, 10 of them being endemic (Rakhmatullaev 2002) (**Table 3**). In subtropical and tropical regions there is a wider variation in species rather than species richness (Kale and Seenappa 1997). Eleven species have been reported from cultivated, non-cultivated, grassland, and garden soils (Singh 1997).

The species *A. svetlovia taschkentensis*, *A. svetlovia ferganae*, *A. svetlovia kaznakovi* and *A. roseus* are endemic to Uzbekistan. The poor diversity of earthworms in Uzbekistan soils may be attributed to climatic conditions, as well as soil properties of the region, since Uzbekistan climate is hot and dry (arid), and the texture of soil in this arid region is primarily clay Lee (1985) reported earlier that earthworms are generally absent or rare in soils with coarse texture probably due to the susceptibility of such soils to drought. *A. trapezoides* and *A. caliginosa* are widely distributed in the entire Uzbekistan area and appear to be better adapted to withstand drought conditions. In general, earthworm diversity is higher in natural systems than in interfered habitats (Lee 1985), also stable ecosystems are reported to have a higher species diversity compared to unstable environments (May 1979). Tripathi and Bhardwaj (2004) reported that grassland was dominated by a single species such *M. pothuma*, *L. mauritii*, *A. morrisi*, and *O. occidentalis.*

Rakhmatullaev and Mavlanov (1999) studied the distribution of 5 dominant species of earthworms (*A. caliginosa*, *A. trapezoides*, *A. jassyensis*, *Dendrobaena byblica* and *Octolasion lacteum*) under lucerne in serozem soils of Uzbekistan. They found that in spring the number of earthworms was higher at 0-10 cm soil depth. Species of earthworms such as *A. svetlovia taschkentensis*, *A. svetlovia kaznakovi*, *A. svetlovia ghilaravi*, *D. byblica*, *A. caliginosa trapezoides*, *A. caliginosa caliginosa*, *A. roseus*, *D. veneta*, *Eisenia fetida*, *Eiseniella tetraedra* and *O. lacteum* are distributed in the mountain areas of the north eastern part of Uzbekistan. *A. jassyensis* was present only in valleys and lowland areas where soil was characterized as calcareous serozem.

Mandrugin and Akhmerov (1994) studied earthworm parasites which play a role in regulating earthworm populations. They found that *A. caliginosa* are more infected with *Amobotaenea cuneata*. Ikramov *et al.* (2001) reported that *E. foetida*, *D. byblica* and *D. veneta* are infected with *A. cuneata*, *Ascaris galli* and *Paracuarua* sp., mostly in summer.

Table 3 Earthworm species distributed in Uzbekistan [b] soils.

Genus	Species
Allolobophora	*Allolobophora (S)* [a] *taschkentensis*
	A.(S.) kaznakovi
	A.(S.) ferganae
	A.(S.) arnoldiana
	A.(S.) chlorocephala
	A.(S.) microtheca
	A.(S.) graciosa
	A.(S.) umbrophila
	A.(S.) ophimorpha
	A.(S.) stenosoma
Aporrectodea	*Aporrektodea roseus*
	A. caliginosa caliginosa
	A trapezoides
	A. jassyensis
Eisenia	*E. fetida*
	E. nordenskioldi
Eisenilla	*Eiseneilla tetraedra*
Dendrobaena	*Dendrobaena veneta*
	D. byblica
Dendrodrilus	*Dendrodrilus rubidus tenuis*
Octolasion	*Octolasion lacteum*

[a] (*S*) *Svetlova*, [b] Data from Rakhmatullaev and Mavlanov (2001)

Table 2 The effect of crop rotation on the abundance of earthworms [a] in Uzbekistan soils,

Crop	The number of earthworms (1 м^2)				The number of earthworms (ha^{-1})
	Year	April	July	October	
Cotton	1995	15.6	7.5	12.3	113.000
Lucerne 1 year	1996	14.4	8.2	13.1	119.000
Lucerne 2 year	1997	145.5	115.1	137.3	1.226.000
Lucerne 3 year	1998	250.2	190.4	235.5	2.240.000

[a] Data from Rakhmatullaev and Mavlanov (1999)

THE EFFECT OF FERTILIZERS ON EARTHWORM POPULATION

Earthworms can be favorably or adversely affected by different agricultural practices. Whereas heavy cultivation is detrimental to earthworm populations, reduced and no-tillage agricultural practices promote the growth of earthworm populations (Bohlen 2002). Auerswald *et al.* (1996) reported that of all the soil properties considered to influence the population and activity of earthworms, the relative abundance and biomass of earthworms appears to decrease with a decrease of soil moisture and soil acidity (pH > 7). Tripathi and Bhardwaj (2004) reported that the western dry region of India comprises very poor earthworm diversity, mostly for highly degraded soils, i.e., the soil moisture, organic carbon and nitrogen were found to be significantly correlated with the distribution of the worms. Adigun *et al.* (2008) found that the cation exchange capacity (CEC), total N, Cu and soil moisture content significantly ($p < 0.05$) affected the species distribution of earthworms, their lengths and weights.

Most earthworms prefer a pH of 6.0-7.0 while the species diversity is drastically reduced at pH > 7.0 except for tolerant species, which may be due to the fact that soil with pH considerably higher than 7.0 are mostly semiarid or arid and are unfavourable for earthworms (Lee 1985; Karmegam and Daniel 2007). Edwards and Lofty (1977) suggest that earthworm species generally tolerate a narrow range in pH, very few specialized to highly acidic soils (pH 4). Most of them prefer neutral soil pH, but only few species can tolerate acidic, or alkaline soils (Tripathi and Bhardwaj 2004). Several pesticides, insecticides and soil fumigants are very or highly toxic to earthworms. Furthermore, soil contamination with organic pollutants, heavy metals, and acid precipitation can be detrimental to earthworm populations (Bohlen 2002). Increased soil organic carbon content correlated with an increase of biomass and population of earthworms (Hendrix *et al.* 1992; Auerswald *et al.* 1996). Mavlanov and Rahmatullaev (1999) studied the effect of organic and mineral fertilizers (N – 180; P – 200; K – 120 kg/ha; manure – 30 t/ha) on earthworm populations under lucerne cultivation. In their studies, the application of organic fertilizers increased the population of earthworms. Also in a study of Bohlen (2002) organic amendments, such as animal or green manures, stimulated the growth of earthworm populations. In contrast, the application of chemical fertilizers in arid soils reduced the number of earthworms (**Table 4**). It has been previously reported that the long-term application of inorganic fertilizers may adversely affect earthworm populations due to soil acidification or other changes in the soil environment (Bohlen 2002).

In general, the numbers of earthworms were increased during the autumn period, whereas they decreased during summer. In earlier studies, Nordström and Rundgren (1974) reported that high surface temperature and dry soils are the most limiting factors to earthworms. Moreover, the deep tillage used in crop cultivation decreased their population, whereas no-till cultivation supported higher number of earthworms.

THE EFFECT OF EARTHWORMS ON CROP PRODUCTIVITY

Nutrient depletion of soil is a particular problem for small holder agriculture in developing countries, where mostly grain-legume production occurs and many farmers cannot afford to use inorganic fertilizers. Several authors have reported that earthworms may promote soil fertility and plant growth (Edwards and Bohlen 1996; Wardle *et al.* 1999). In previous studies of nutrient poor soils, Alimdjanov (1963) reported that earthworms influence crop productivity positively. More recently, Rahmatullaev (2002) studied the effect of earthworms, *A. caliginosa caliginosa* in arid soils on the growth and development of tomato and barley (**Table 5**). The yield of tomato was increased from 39 to 133% compared to the control plot without earthworms. Similarly, the germination and growth of cotton, maize and lucerne were stimulated in soil with higher number of earthworms (Marshall 1973). In general, beneficial effects of earthworms on plant growth may be due to increased nutrient and water availability, improved soil structure, stimulation of microorganisms or increased formation of microbial products that enhance plant growth, or possibly through direct production of plant growth promoting substances (Bohlen 2002). Earthworms directly improve the aeration and porosity of soil through formation of burrows and by increasing the proportion of large aggregates in the soil, which is an effects especially important in poorly structured or reclaimed soil (Bohlen 2002). Thus, they can facilitate preferential flow of water through the soil profile,

Table 4 The effect of tillage and of chemical and organic fertilizers on earthworm populations (under cotton cultivation).

Treatments	Soil depth, cm	The number/weight of earthworms (1 м², g)			Total
		May	July	September	
Control	0-30	12.3/1.550	8.1/1.664	12.2/1.388	32.6/4.622
	30-60	16.1/10.208	8.4/1.600	4.7/0.916	29.2/12.724
Manure	0-30	84.2/16.464	40.10/8.160	56.1/17.824	180.3/42.448
	30-60	16.9/6.720	10.2/2.000	12.8/1.548	39.3/10.268
NPK	0-30	52.1/13.076	36.0/7.344	40.4/2.680	121.1/22.110
	30-60	12.3/3.228	20.3/4.080	12.5/7.800	45.1/15.108

[a] Data from Mavlanov and Rakhmatullaev (1999)

Table 5 The effect of earthworms on the productivity of tomato.[a]

Treatments	Plant growth		The number of fruits per plant		Yield/plant	
	cm	%	No.	%	g	%
Control	45.5 ± 4.0	100	9	100	750 ± 60	100
20 earthworms per m²	49.2 ± 5.4	108	12	133.3	1047 ± 112	139.6
40 earthworms per m²	50.3 ± 4.2	110	19	211.0	1750 ± 142	233.3
0.5 kg manure per m²	55.2 ± 4.1	121	15	166.5	1302 ± 140	173.5

[a] Data from Rakhmatullaev (1999)

Table 6 The effect of earthworms on the growth and yield of barley. [a]

Treatments	Shoot length, cm	%	Dry weight (g)	%	Yield (g)	%
Control	53.1 ± 0.5	100	6.1 ± 0.58	100	3.5 ± 0.27	100
4 earthworms per m2	64.5 ± 0.5	121	8.5 ± 0.53	139	4.2 ± 0.3	120
8 earthworms per m2	67.2 ± 5.4	126	10.1 ± 0.82	165	6.6 ± 0.5	188
12 earthworms per m2	71.1 ± 6.3	133	12.1 ± 1.3	198	7.3 ± 0.6	208

a Data from Rakhmatullaev (1999)

increasing the transport of water, nutrients, and agricultural chemicals into deeper soil layers. They also facilitate the breakdown and mineralization of surface litter (Edwards *et al.* 1992; Subler *et al.* 1997).

With respect to productivity, earthworms are reported to effect positively the growth and productivity of barley, increasing yields up to 70% (**Table 6**). Furthermore, earthworms have been shown to increase the production of shoots and grain of cereals in a variety of field trials and greenhouse experiments. The introduction of earthworms into reclaimed polders in the Netherlands, or into pastures in New Zealand resulted in large increases in forage quantity and quality (Stockdill 1982; Hoogerkamp *et al.* 1983).

CONCLUSION

This report presents ecological information about the role of earthworms in saline arid soils of Uzbekistan. The effects of land management practices on earthworm populations are also discussed. The abundance and diversity of earthworms in arid soils are low due to the susceptibility to drought and salinity of such soils. Crop rotation and application of organic fertilizers positively effects earthworm populations. Thus to reduce chemical fertilizers in crop production increase earthworm population through soil biological properties and productivity also improves.

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