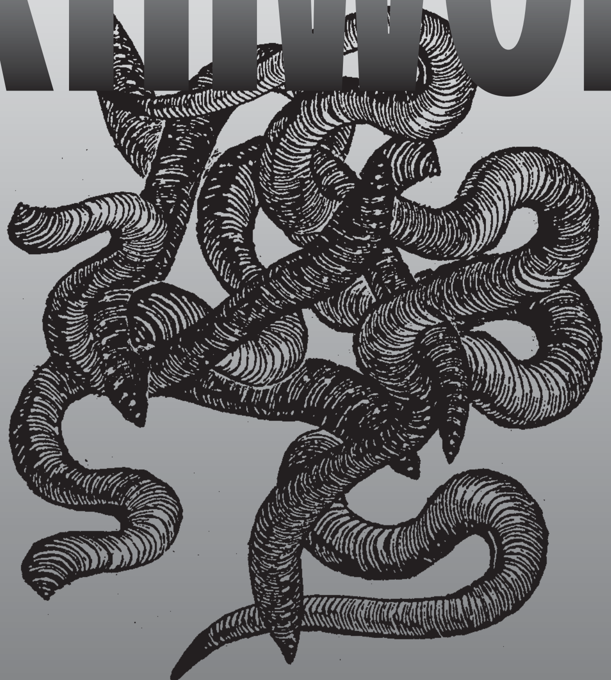
Earthworms

EARTHWORMS



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EARTHWORMS

WHY ARE EARTHWORMS IMPORTANT?

Only a few decades ago, the predominating thought was that earthworms were not very important for agriculture. Emphasis was placed on physical and chemical aspects of plant growth while biological aspects were neglected. We are now realizing how interactions between crops, climate, soil, and living organisms play important roles in sustaining our agriculture. Earthworms are among the most visible of soil organisms and have received considerable attention. They play a pivotal role in maintaining the productivity of our soils. This makes understanding these lowly animals and finding ways to make them thrive very important.

Benefits of earthworms

The burrowing and feeding activity of earthworms have numerous beneficial effects on overall soil quality for crop production. The following soil properties can be improved by earthworms.

Water infiltration

Some earthworm species create vertical burrows, whereas other species live in horizontal burrows in the soil. The vertical burrows are typically open, although the worms cap the top with residue and excrement. The vertical burrows are very important points of entry for quick water infiltration into the soil, especially in no-till systems.

Soil aeration

Air-filled porosity is critical in helping plant roots to thrive. Roots need oxygen for their growth, whereas they produce carbon dioxide that needs to leave the soil. Because earthworms improve soil porosity, they improve the exchange of these gases with the atmosphere. Earthworms increase porosity by two mechanisms: (1) by creating permanent burrows, and (2) by improving soil aggregation. Aggregation is improved by the mixing of soil and organic matter in the earthworms' guts. These highly stable aggregates are deposited by some earthworms in their burrows, and by others at the surface of the soil. In one pasture study, earthworms consumed between 20 and 40 tons of soil per acre per year. In another study, earthworms were estimated to consume 4 to 10 percent of the top 6 inches of the soil annually. This only goes to show the enormous amounts of soil that can be processed by earthworms.

Soil compaction and soil tilth

Soil compaction reduces the porosity of the soil. Because earthworms increase porosity, they reduce the effects of compaction. In addition, the excrement of earthworms has a very stable structure, which makes the soil more resistant to compaction and improves its tilth.

Soil organic matter

Typical earthworm populations can easily consume 2 tons of dry matter per acre per year, partly digesting and mixing it with soil. The importance of earthworms to mix surface residue with soil becomes very clear in soils that do not have any earthworms. Most of our Pennsylvania soils have at least some earthworms and the effect of their complete absence therefore cannot be noted. In the Netherlands, some soils reclaimed from the sea at first did not have any earthworms. In these soils the formation of topsoil with reasonable organic matter content did not take place, resulting in poor crop growth. Once the cause was established, the government of the Netherlands started a campaign to introduce earthworms. After the introduction of the earthworms, a dark topsoil layer was formed, and crop growth increased substantially.

Plant available nutrients

Earthworm casts have higher available nitrogen, phosphorus, potassium, and calcium contents than surrounding soil, as well as a higher cation-exchange capacity. Some micronutrients, such as zinc and boron, are more available in the excrement of earthworms through chelation of the micronutrients.

Soil pH

Soil passed through the gut of earthworms has a neutral pH. This is probably due to the pH buffering action of organic molecules produced in the gut of worms.

Beneficial microbes

Earthworms excrete material that has high concentrations of beneficial microbes that help decompose crop residue.

Nematode control

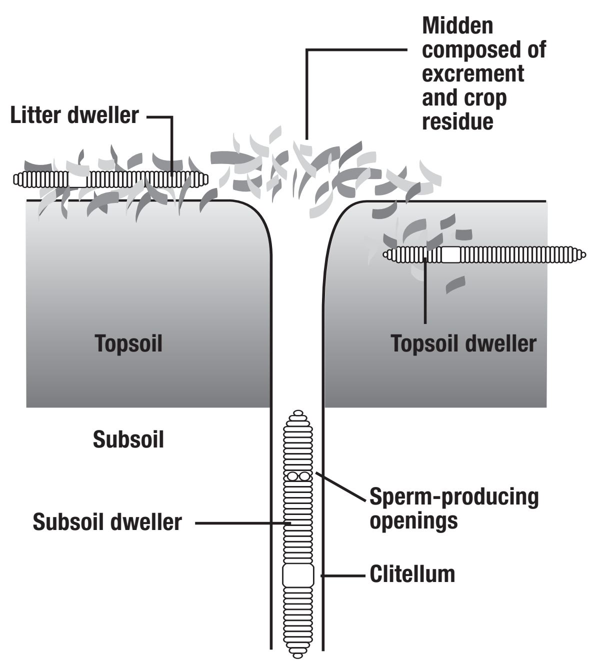
Some earthworms eat harmful nematodes, thus decreasing the concentration of these harmful organisms in soil.

TYPES OF EARTHWORMS

There are more than 1,000 different earthworm species, but they can be placed into one of three groups (Fig. 1):

1. **Litter dwellers** or *epigeic* species live in crop or forest litter. They are not common in most agricultural soils. These species do not ingest large amounts of soil. The manure or red worm, *Eisenia foetida*, is an example of a litter dweller.
2. **Topsoil dwellers** or *endogeic* species live in the upper 2 to 3 inches of the soil. They live primarily from partially decomposed organic matter that is already incorporated in the soil. They eat their way through the soil, creating horizontal burrows that they fill with their excrement. These species ingest large amounts of soil that they mix with digested crop residue in their guts.
3. **Subsoil dwellers** or *anecic* species live in permanent vertical burrows that can be 5 or 6 feet deep. These earthworms need surface crop

FIGURE 1. THREE MAJOR GROUPS OF EARTHWORMS ARE: LITTER DWELLERS, TOPSOIL DWELLERS, AND SUBSOIL DWELLERS



residue to live. Their burrows remain open, although they cap the top with crop residue that they pull to the entrance. These species ingest substantial amounts of soil that they mix with digested residue in their guts. Their excrement is primarily deposited at the surface of the soil. The nightcrawler *Lumbricus terrestris* is the most prominent member of this group.

EARTHWORM BIOLOGY

Earthworms are invertebrates composed of many segments (Fig. 1). They don't have bones and move by contracting and relaxing the body segments in sequence. They also have little bristle-like organs that help them cling to slippery surfaces. Most earthworms have both male and female organs. Typically, however, they still need a partner to reproduce. When earthworms mate, they lay side by side in reverse position. At that moment they exchange sperm. The sperm of the partner is stored in little chambers called spermathecal apertures. These are positioned in front of the egg-producing organs. After mating, the swollen external gland, called clitellum, produces egg cases called cocoons. A cocoon case slides slowly forward, picking up eggs and sperm as it moves over the head of the earthworm. From 3 to 1,000 cocoons can be produced per year, depending on species and environmental conditions. Typically, an earthworm will produce 20 to 30 cocoons per year, with each cocoon containing 1 to 10 eggs. Peak cocoon production is in the spring or early summer. The eggs in the cocoons hatch when conditions are right. Under ideal conditions, it may take from 1 to 5 months for the eggs to hatch. It may then take from 3 to 12 months before these worms are sexually mature. Worms typically live only a few months because of the many environmental threats they face. They have been observed to live for 10 years in a protected environment. In a favorable environment previously without earthworms, earthworm populations increased 80-fold in 4 years after introduction.

ENVIRONMENTAL EFFECTS ON EARTHWORMS

The burrowing and feeding activity of earthworms, as well as their overall population, are affected by the soil environment in which they live. Some of the properties important to earthworms include the following.

Moisture

Earthworms absorb and lose moisture through their skin. If soils are dry, earthworms may move to deeper soil layers, die, or revert to a hibernation condition called diapause. Earthworms in diapause are tied up in a knot in a little hole that is lined with a slimy substance to avoid moisture loss. Eggs in cocoons survive prolonged drought, allowing earthworm populations to survive drought periods. Because of dry conditions, earthworm populations in Pennsylvania are low in the summer. Earthworms can live under submerged conditions if the oxygen content of the water is high enough. In most cases, however, earthworms will die when exposed to excessive waterlogging. They move to the surface when the soil is saturated to avoid suffocation.

Temperature

Most earthworms don't tolerate temperatures below freezing, nor do they tolerate high temperatures. Prolonged exposure to temperatures above 95°F kills them. They can move down into the soil to escape these adverse temperatures. Optimum temperatures are between 50 and 60°F.

pH

Earthworms commonly found in agricultural fields thrive at neutral pH, but can tolerate a pH from 5.0 to 8.0.

Soil texture

Earthworms prefer soils with loamy texture. Coarse sand can be a negative factor either because the abrasive action of sand grains damages their skin, or because these soils dry out more easily. In some studies, clay soils had fewer earthworms than lighter-textured soils. The reason for this phenomenon is not clear.

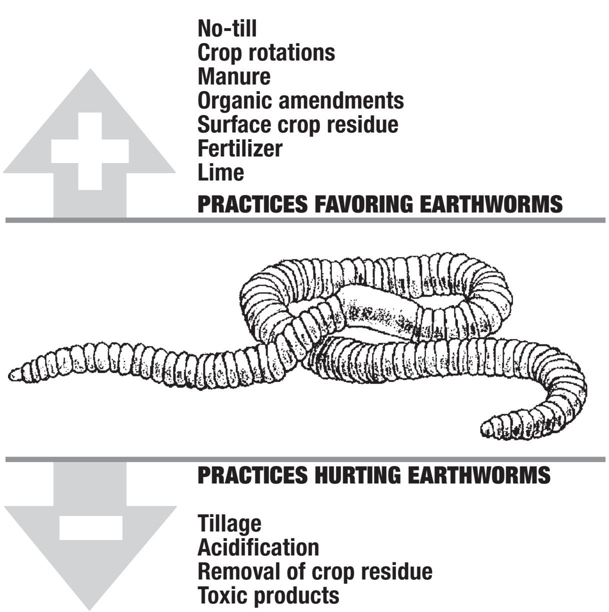
Food supply

Quantity, quality, and placement of food influence earthworm populations. Earthworms eat organic residue that needs to be present in sufficient quantity. The quality of residue is also important. Residue with a high carbon to nitrogen (C:N) ratio is not very palatable for earthworms. Manure can help make it more palatable. Packed manure is an excellent food source for earthworms. In some cases, residue has to undergo some weathering before earthworms are able to digest it. Topsoil dwellers need smaller particles than subsoil dwellers, which can use large leaves, for example. The placement of food becomes a critical issue for some earthworm species. Topsoil dwellers prefer small organic residue particles incorporated into the soil, but subsurface dwellers need residue at the surface of the soil.

MANAGEMENT EFFECTS ON EARTHWORMS

Soil and crop management practices can influence many soil properties that affect earthworms (Fig. 2). Some practices can have immediate effects on earthworms, whereas others may gradually change earthworm population and activities over several years. So when you are considering management options, you should also think about their effects on earthworms. Some of the more important management effects on earthworms are described below.

FIGURE 2. MANAGEMENT PRACTICES FAVORING/HURTING EARTHWORMS



Tillage

Soil tillage greatly affects earthworms (Table 1). The burial of crop residue and manure by tillage favors topsoil dwellers over subsoil dwellers. In long-term clean-tilled fields, nightcrawlers are scarce. Tillage also stimulates drying the surface soil and wide day/night temperature fluctuations. This is another reason earthworms are less numerous in clean-tilled fields compared to no-tilled fields. Tillage brings earthworms to the surface where they are subject to predators such as birds. Total earthworm populations in long-term no-tilled fields are typically at least twice those of clean-tilled fields.

TABLE 1. EARTHWORM POPULATIONS AS AFFECTED BY MANAGEMENT

Tillage	Management	Earthworms/ Acre
Continuous corn	Plow	39,000
Continuous corn	No-till	78,000
Continuous soybeans	Plow	235,000
Continuous soybeans	No-till	549,000
Bluegrass-clover	Alleyway	1,568,000
Dairy pasture	Manure	1,333,000
Dairy pasture	Manure (heavy)	5,097,000

From *Earthworms and Crop Management* by E. J. Kladivko, 1993. Purdue University Cooperative Extension Service Agronomy Guide AY-279. Crop and management systems had been continuous for at least 10 years.

Crop rotation

Providing earthworms with a diverse diet is important. Crop residue of leguminous species (low C:N ratio) is more palatable to earthworms than that of mature grass and grain species (high C:N ratio). However, a legume such as soybean produces very little crop residue, which limits the quantity of food available to earthworms. Earthworms thrive in grasslands and alfalfa. In one grassland study, 70 earthworms were counted per square foot (more than 3 million earthworms per acre).

Crop residue

If crop residue is removed, earthworms lose their food source. Use of a cover crop that is left in the field or removal of only part of the crop are ways to feed earthworms.

Manure

Manure is a food source for earthworms. It also makes crop residue with a high C:N ratio more palatable to earthworms. Manure stimulates crop residue production because of its fertilizing effect, increasing the food supply for earthworms. Liquid manure can have a temporary depressing effect on earthworms due to its ammonia and salt content. After this effect has subsided, however, earthworm populations tend to increase.

Organic amendments

Sludge and compost can greatly stimulate earthworm populations by providing a quality feedstock for them.

Fertilizer and lime

There is good evidence that most inorganic fertilizers favor the buildup of large numbers of earthworms, probably due to the increased amounts of crop residues being returned to the soil. Anhydrous ammonia and ammonium sulfate have been found to have negative effects on earthworms. This may be due to the acidifying effect of this fertilizer, but also due to the toxic effect of ammonia. Liming to neutralize acidity stimulates earthworm activity.

Pesticides

The effects of pesticides on earthworms depend on the type of pesticide and its rate of application, earthworm species and age, and environmental conditions. Appendix 1 gives test results of pesticide toxicity on earthworms. The studies simulated normal exposure rates of pesticides commonly used in field crops. The table summarizes a great number of different studies that used widely varying methods of evaluation and should therefore be used with caution.

Most inorganic chemicals tested are no longer in use as pesticides. Based on the limited amount of information available, these chemicals do not seem to be very toxic to earthworms, except when they accumulate in soil over a long period of time. Organochlorine insecticides were extensively used from the 1950s to the1970s, but are not used in large quantities today. Endosulfan and lindane are moderately toxic and probably toxic at normal exposure rates, respectively. Some organophosphate insecticides, such as acephate, azinphos methyl, chlorpyrifos, ethoprophos, ethyl-parathion, and phorate are very toxic to earthworms. The other organophosphate insecticides listed are nontoxic to moderately toxic to earthworms. Carbamate insecticides and fungicides are very toxic to earthworms. Carbaryl and carbofuran, both commonly used in field crop production, are extremely toxic to earthworms. Pyrethroid insecticides, on the other hand, have not been found to be toxic to earthworms. Most contact fumigant nematicides/fungicides are broad-spectrum biocides that will kill most earthworms, even those living deep in the soil. Of the other fungicides tested, none were found to be toxic to earthworms except carbamate fungicides such as benomyl and carbendazim (not listed). Most herbicides are nontoxic to earthworms, although some, such as 2,4-D, pendimethalin, and simazine, are toxic at high exposure rates.

Similar to that of humans, pesticide health risks to earthworms depend not only on the toxicity of the chemical but also on the exposure to it. On the other hand, earthworms that crawl on the soil surface (such as nightcrawlers) have a higher exposure to surface-applied pesticides than those feeding and burrowing below the soil surface. On the other hand, pesticides injected in a small slot in the soil (such as the seed slot) may not come in contact with many earthworms and therefore will not pose a significant threat for the population at large. Remember that earthworms are most active in the spring and fall under favorable temperature and moisture conditions. Pesticide application during these periods is most likely to pose a threat to earthworms. If the soil is moist, earthworms will be more active and therefore more likely to come into contact with pesticides. The effects of pesticides on earthworms also depend on age of the earthworms. Juvenile earthworms are more sensitive to pesticides than adults because they move slower and are not able to burrow away deep into the soil.

APPENDIX. SUMMARY OF LAB AND FIELD DATA ON TOXICITY OF CHEMICALS TO EARTHWORMS

Chemical	Trade name	Relative toxicity*	Comments
Inorganic chemical			
Copper sulfate	Mastercop Ramenox P.B.	0	Persistent, toxic at high rates
Sulfur	Kumulus	2	
Biological agents			
Enterobacterin		0	
Mowrah meal		0	Expels earthworms from soil
Rotenone	Nicouline Tubatoxin	0	Expels earthworms from soil
Mustard		ND	Probably nontoxic
Aromatic and organochlorine insecticides			
Endosulfan	Thiodan Phaser	2	
Lindane		ND	Probably toxic
Organophosphate insecticides			
Acephate	Orthene	ND	Probably toxic
Azinphos methyl	Guthion Sniper	ND	Probably toxic
Chlorpyrifos	Lorsban	3	
Chlorpyrifos-methyl	Reldan	ND	Probably nontoxic
Diazinon	Diazinon	1	
Dimethoate	Cygon Dimethoate	1	
Disulfoton	Disyston	1	
Ethoprophos	Mocap	3	
Ethyl-parathion		3	
Fonofos	Dyfonate	2	
Malathion	Cythion Malathion	1	
Methyl-parathion	Penn Cap	ND	Probably nontoxic
Phorate	Thimet	4	
Terbufos	Counter	2	
Carbamate insecticides			
Carbaryl	Sevin	4	
Carbofuran	Furadan	3	
Methomyl	Lannate	4	
Synthetic pyrethroids and chitin inhibitors			
Alphamethrin	Ammo, Cymbush	ND	Probably nontoxic
Diflubenzuron	Dimilin	0	
Es Fenvalerate	Asana	0	
Permethrin	Ambush Pounce	ND	Probably nontoxic
Pyrethrins (unspecified)		ND	Probably nontoxic
Fungicides			
Captan	Captan Rival	1	Seed treatment

SUMMARY OF LAB AND FIELD DATA ON TOXICITY OF CHEMICALS TO EARTHWORMS (continued)

Chemical	Trade name	Relative toxicity*	Comments
Chlorthalonil	Bravo	2	Foliar
Imazalil	Double R Double RII	ND	Seed treatment, probably toxic
Mancozeb	Manzate Penncozeb Dithane	0	Foliar
Maneb	DB-Green Enhance Plus	ND	Foliar, probably nontoxic
Propiconazole	Tilt	ND	Foliar, probably toxic
Thiabendazole	RTU	3	Seed treatment
Thiram	Thiram Vitavax 200 Agrosol T Stiletto RTU	0	Seed treatment
Herbicides			
Atrazine	Aatrex Basis Gold	0	
Bromacil	Hyvar	0	
2,4-D	Butoxone Weedone	1	Toxic at high exposure rates
Dicamba	Banvel Trooper	ND	Probably nontoxic
Diquat	Weedtrine Reglone Reglox	ND	Probably nontoxic
Diuron	Karmex	0	
Glyphosate	Roundup	0	
Hexazinone	Velpar	ND	Probably nontoxic
Linuron	Lorox Linuron	0	Probably slightly toxic
Maleic hydrazide	Regulox Stunt Man	0	Probably slightly toxic
MCPA	MCPA	0	Probably slightly toxic
MCPB	Butoxone M40	ND	Probably nontoxic
Mecoprop	CMPP	ND	Probably nontoxic
Metribuzin	Lexone Sencor Axiom	ND	Probably nontoxic
Paraquat	Gramoxone	0	Probably nontoxic
Pendimethalin	Prowl Pendulum	ND	Probably toxic
Simazine	Princep	2	
Terbacil	Sinbar	0	
Triclopyr	Turflon	ND	Probably nontoxic
Trifluralin	Treflan Tri-4 Trust	0	

* 0 = Nontoxic, 1 = slightly toxic, 2 = moderately toxic, 3 = very toxic, 4 = extremely toxic, ND = not enough data to categorize

Sources: *Biology and Ecology of Earthworms* by C. A. Edwards and P. J. Bohlen, 1996 (Chapman & Hall, London, UK) and *The farmer's earthworm handbook*, by David Ernst, 1995 (Lessiter Publications, Inc., Brookfield, Wis.).

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CONCLUSION

Earthworms are an important part of the soil ecosystem. They help improve soil structure and soil chemical and biological properties. They are especially important in no-till, helping to stimulate air and water movement in soil. Earthworms tend to thrive most without tillage, if sufficient crop residue is left on the soil surface. Crop rotations, cover crops, manure, fertilizer and lime applications all affect earthworm populations. Some pesticides, especially organophosphates and carbamates, are toxic to earthworms. Most herbicides do not pose a threat to earthworms.

Prepared by Sjoerd Duiker, assistant professor of soil management and applied soil physics, and Richard Stehouwer, assistant professor of environmental soil science.

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