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Agricultural Management Effects on Earthworm Populations

Introduction: Earthworm habits and their effects on soil

Many people consider earthworms to be an indicator of soil quality because they respond to and contribute to healthy soil. For earthworms to be abundant, a field must meet several conditions that are also associated with soil quality and agricultural sustainability: moderate pH, surface residue for food and protection, and soil that is not waterlogged, compacted, droughty, or excessively sandy. Not all healthy soils will have earthworms. Worms are not common in sandy soils, in drier regions of the southern and western United States, and in local areas where earthworms have not yet migrated or been introduced by human activities.

Earthworm species vary in how they get food, and thus inhabit different parts of the soil, and have somewhat different effects on the soil environment. They fall into three distinct ecological groups based on feeding and burrowing habits. Epigeic (litter dwelling) earthworms live and feed in surface litter. They move horizontally through leaf litter or compost with little ingestion of or burrowing into the soil. These worms are characteristically small and are not found in low organic matter soils. *Lumbricus rubellus* is an example of epigeic species. Endogeic (shallow dwelling) earthworms are active in mineral topsoil layers and associated organic matter. They create a three-dimensional maze of burrows while consuming large quantities of soil. The genuses *Diplocardia* and *Aporrectodea* have endogeic life habits. Anecic (deep burrowing) earthworms live in permanent, nearly vertical burrows that may extend several feet into the soil. They feed on surface residues and pull them into their burrows. *Lumbricus terrestris* is an example of an anecic species (Coleman and Crossley, 1996). Once established, earthworms contribute to soil function. They:

- Shred residues, stimulating microbial decomposition and nutrient release;
- Produce casts rich in N, P, K, and other nutrients;
- Improve soil stability, air porosity and moisture holding capacity by burrowing and aggregating soil;
- Turn soil over and may reduce the incidence of disease by bringing deeper soil to the surface and burying organic matter;
- Improve water infiltration by forming channels and promoting soil aggregation; and
- Improve root growth by creating channels lined with nutrients for plant roots to follow.

Both endogeic and anecic species are important in contributing to these functions in agricultural systems. The shallow dwellers improve topsoil porosity and the deep burrowing earthworms improve infiltration and drainage.

Earthworms may have undesirable impacts if they remove too much surface residue and leave the soil surface unprotected, or if their burrows open into surface irrigation furrows. There is also some concern that earthworms may enhance the "preferential flow" of herbicides and other pollutants down burrows and into groundwater, causing water to pass too rapidly through the soil matrix. When their total effect is considered, however, earthworms are unlikely to have a significant negative impact on water quality. Where they are active, earthworms may bury herbicide-tainted residue before it has a chance to leach down through burrows. Earthworms may act as plugs in their own burrows, and, in the case of the herbicide atrazine, earthworm-feeding activity may actually change the chemical to reduce its mobility (Farenhorst et al., 2000). In addition, earthworm activity improves soil structure and therefore reduces runoff of chemicals into surface water. Another concern is that fresh earthworm casts on the surface are unstable and may lead to higher soil erosion and nutrients in runoff. Earthworm casts stabilize as they age so that the risk of erosion is greatly reduced. In summary, earthworms affect soil function in multiple ways. In specific situations they may have undesirable effects, but predominately they contribute to improved soil quality and are a sign of a healthy, properly functioning soil.

What determines earthworm abundance?

The number of earthworms in an agricultural field is influenced by the intensity and number of soil disturbance events like tillage and traffic, the abundance and quality of food sources, the chemical environment of the soil, and the soil microclimate. Important factors of the soil environment include:

- *Organic matter (food sources)* – Higher inputs of fresh organic matter are associated with greater earthworm populations.
- *Soil type* – Populations are highest in medium textured soil.
- *Depth to a restrictive layer* – Earthworms prefer deeper soil.
- *Soil pH* – In general, earthworms will not thrive in a soil with a pH below 5 (Edwards and Lofty, 1977).
- *Moisture holding capacity and internal drainage* – Earthworms need moist but well-aerated soil.
- *Rainfall and temperature* – Climate affects the soil environment and food sources (plant biomass) for earthworms.
- *Predation and parasitism*.
- *Earthworm introduction* – Even where environmental factors are favorable, earthworms may not have migrated and established populations.

When all other factors are equal, the availability of plant litter and organic matter is usually the most important in determining earthworm abundance, but any of the other factors may override the influence of organic matter.

Many management practices affect earthworm populations because they change one or more of the environmental factors listed above. This technical note will examine the effects of six components of management: (1) tillage, (2) crop rotations and cover crops, (3) fertilizers, (4) pesticides, (5) irrigation and drainage, and (6) worm seeding (inoculation).

Tillage

As the number and intensity of tillage operations increase, so does the physical destruction of burrows, cocoons, and the earthworm bodies themselves. Less intensive tillage systems that leave residues on the surface throughout the year improve the environment for earthworms. The residues provide food, insulate earthworms from weather conditions, provide cover to protect them from birds and other surface predators, and protect their burrows. Decreased tillage disturbances particularly benefit night crawlers (*L. terrestris*), which move in the same burrow between deeper soil layers and the soil surface in search of food. When tillage destroys the burrow, some earthworms will not have the energy reserve to form a new burrow to their food source. Endogeic (shallow dwelling) earthworms will tolerate annual tillage because they continually form new burrows and acquire a greater proportion of their food from the soil rather than surface litter. No-till and other methods of conservation tillage such as chisel plowing and ridge tillage can increase populations of both types of earthworms (Edwards and Bohlen, 1996) (Table 1).

Although a single tillage event will not drastically reduce earthworm populations, repeated tillage over time will cause a decline in earthworm populations.

Research has found the following:

- Earthworms were reduced by 70% compared to previously undisturbed sod after five years of plowing (Edwards and Bohlen, 1996).
- After 25 years of conventional tillage crop production earthworm populations were only 11-16% of what existed in the original grass field (Edwards and Bohlen, 1996).
- Edwards et al. (1995) reported up to 30 times more earthworms in no-till systems compared to plowed fields.
- In Nigeria, researchers found 2400 earthworm casts/m^2 in no-till plots compared to 100 casts/m^2 under conventional tillage (Edwards and Lofty, 1977).
- In a Georgia experiment, no-till fields had an average of 967 earthworms/m2 compared to 149 /m2 in conventionally tilled fields (Coleman and Crossley, 1996).

Table 1. Earthworm Populations (No./yd^2) as influenced by amount of surface residues at Langdon Research and Extension Center, ND (Ernst, 1995).

	40 - 45% Residue	80 – 90% Residue
Earthworms	71	106
Cocoons	204	514
Total	275	620

Crop Rotations and Cover Crops

Tillage affects decomposition and availability of surface residue, while choice of crop determines the quantity and quality of the residue as a food source for earthworms. Earthworm populations will decrease to very low numbers under an exhaustive cropping system of plowing, crop residue removal, and no additions of manure or other organic inputs.

There is a strong correlation between earthworm numbers and the amount and quality of residue returned to the soil. (Table 3.) Generally, cereal crops such as wheat (especially if straw is returned to the soil) encourage earthworms more than crops which leave less residue such as soybean. Studies in the 1940's showed the following ranking in order of earthworm population (all are conventionally tilled cropping systems): pasture = small grains followed with legume hay grown in the summer > small grains with summer fallow > drilled soybeans for grain > soybeans for hay > corn (Hopp and Hopkins, 1946). At the Rothamsted Experimental Station in England where crops have been studied since 1843, the largest earthworm populations occur under continuous cereals, were lower under root crops such as turnip, and were the lowest under fallow (Edwards and Bohlen, 1996).

Despite its high residue production, continuous corn supports fewer earthworms than when in rotation with soybeans, whether under no-till or conventional tillage. Earthworms seem to prefer legumes (Table 2). Although probably less important, other factors that may discourage earthworms in corn could be soil application of insecticides to control rootworms and anhydrous ammonia fertilizer (Kladivko, 1993).

Crop rotations with pasture or hay greatly increase earthworm numbers. There is a strong correlation between earthworm numbers and years in grass and legumes. For example, a crop every third year in grass rotations will have greater earthworm numbers than a crop every two years or annual cropping. Dick Thompson (Boone, Iowa) followed a 6-year rotation of corn, soybeans, oats, and 3 years of pasture (alfalfa, red clover, grasses, and other forages). He reduced tillage and used livestock manure. Researchers from the Agricultural Research Service National Soil Tilth Laboratory (Ames, Iowa) found more earthworms in Thompson's fields compared to an adjacent neighbor's conventionally tilled field in corn-soybean rotation (Ernst, 1995). The larger earthworm populations were attributed to more food from grass-legume hay crops, manure, and reduced tillage.

Alfalfa and clover in rotations benefit earthworm numbers because of the absence of tillage and the high protein content in their residues. Rotations with alfalfa and grass contain more earthworms than lespedeza and grass, and orchard grass contains more earthworm numbers than timothy grass alone (Hopp and Hopkins, 1946).

Using cover crops helps to increase earthworm populations by increasing their food supply (organic residue) and by giving them a longer season to eat and reproduce. Cover crops insulate worms from cold weather in the fall and from warm weather in southern climates. The extra food and ground cover provided by cover crops are especially important where earthworms are removing a high percentage of crop residue. University of Wisconsin has reported residue cover being reduced from 30% to 15% by earthworms at planting time in no-till fields (Ernst, 1995).

Table 2. Earthworm populations (No./yd^2) under different no-till rotations at Brecker Farm, Havana, ND (Ernst, 1995).

	Wheat-Corn	Corn-Soybeans	Wheat-Soybeans
Earthworms	257	346	443
Cocoons	27	71	35
Total	284	417	478

Table 3. Earthworm populations affected by crop and tillage (Kladivko, 1993).

Crop	Management	Earthworms/m^2
Continuous corn	Plow	10
Continuous corn	No-till	20
Continuous soybean	Plow	60
Continuous soybean	No-till	140
Bluegrass-Clover	Alleyway	400
Dairy pasture	Manure	340
Dairy pasture	Heavy manure	1300

Fertilizers

Nearly all organic fertilizers benefit earthworms. The addition of animal manure, sewage wastes, and spent malt from breweries, paper pulp, or potato processing waste all showed a positive effect on earthworm numbers (Edwards et al., 1995). Additions of organic material can double or triple earthworm numbers in a single year. The ammonia and salt content of some liquid manure can have an adverse effect on earthworms, but populations usually recover quickly and henceforth increase (Edwards and Bohlen, 1996).

Normally, the use of inorganic fertilizers also has a positive impact on earthworm numbers. This is probably an indirect effect of the increased crop biomass production and consequent increases in organic residues (Edwards and Bohlen, 1996; Edwards et al., 1995). Hendrix et al. (1992) reported that earthworm numbers in meadows receiving inorganic fertilizer averaged nearly twice the earthworms in unfertilized meadows on the Georgia piedmont.

Ammonia and ammonia-based fertilizers can adversely affect earthworms. Annual use of ammonium sulfate, anhydrous ammonia, and sulfur-coated urea has been shown to decrease earthworm populations (Edwards et al., 1995). Research at Park Grass (Rothamsted) since 1856 showed that after extremely long exposure to several levels of ammonium sulfate (0, 48, 97, and 145 kg/ha), the populations of earthworms were inversely proportional to the dose of nitrogen applied (Edwards and

Lofty, 1977). This is probably due to the effect these fertilizers have on lowering soil pH. Direct exposure to anhydrous ammonia during application will kill up to 10% of the population. However, farmers report increased numbers in the long run due to higher yields and more food for earthworms to feed upon (Ernst, 1995). Still, some farmers have switched from anhydrous ammonia to 28% nitrogen to avoid killing earthworms during nitrogen application. Others have converted to using manures in order to protect and increase earthworms (Ernst, 1995).

Lime seems to benefit earthworm populations in otherwise acid soils because most species of earthworms favor neutral pH levels and require calcium for growth. Lime may indirectly benefit earthworms by increasing plant growth and therefore plant residues. A study in New Zealand showed a 50% increase in surface feeding earthworm species by adding one ton of lime per acre (Edwards et al., 1995).

Pesticides

In general, most herbicides are harmless to earthworms. The triazine class of herbicides has a moderate impact on earthworm numbers. Herbicides used prior to World War II, including lead arsenate and copper sulfate, are moderately toxic to earthworms. The main threat of toxicity to earthworms is from long-term buildup of these compounds in the soil (Edwards and Bohlen, 1996).

The majority of the carbamate class of insecticides are toxic to earthworms. The toxic effects of carbofuran (Furadan) have been studied extensively. Other insecticides in the carbamate class that have proved highly toxic to earthworms are aldicarb (Temik), aminocarb, bufencarb, carbaryl (Sevin), methiocarb (Measural), methomyl (Lannate), oxamyl (Vydate), promecarb, propoxur (Baygon), and thiofanox. Generally, insecticides in the organophosphate class are less toxic to earthworms. However, organophosphate insecticides that are extremely or highly toxic are phorate (Thimet), chloropyrifos (Dursban, Equity, Tenure, etc.), ethoprophos (Mocap), ethyl-parathion, and isazophos. Aromatic organochlorine insecticides (used predominantly in the 1950's-1970's) are generally not very toxic. Exceptions are chlordane, endrin, heptachlor, and izobenzan. Carbamate fungicides (carbendazim and benomyl) have shown toxic effects to earthworms. Other broad-spectrum fumigants (fungicides and nematicides) are very toxic to earthworms. (Ernst, 1995; Edwards and Bohlen, 1996.)

Irrigation and Drainage

Irrigated soil can support high levels of earthworm activity where moisture levels would otherwise be too dry. Irrigation also increases crop production, resulting in more food and increased earthworm populations. Irrigation waters that carry earthworms and their cocoons may act as a source of inoculum for certain species (Edwards et al., 1995). Draining poorly drained soils will potentially provide a more favorable environment for earthworm activity by aerating the soil.

Seeding Worms

Shallow dwelling earthworms are generally present in agricultural fields, so their populations dramatically increase within one to two years of switching to earthworm friendly practices. However, the deep dwelling night crawlers take longer to increase. Even when favorable conditions have been established, night crawlers must move into unoccupied areas by slow overland migration. Night crawlers are also slow to breed. If left to their own devices, it may take seven to eight years, or longer, for populations to grow (Ernst, 1995).

Seeding earthworms or their eggs may be an option to increase populations in favorable environments. Although some soils, such as extremely coarse sands or heavy clays with a high water table, will not support night crawlers due to inherently adverse soil properties. If a farmer wants to try seeding night crawlers, it is recommended to begin with a low cost, small-scale trial to be sure they survive at a particular site (Kladivko, 1993). Farmers in Indiana and Illinois have seeded 10,000 – 100,000 night crawlers to their farms at a cost of four to five cents per worm from local bait shops and Canadian sources (Ernst, 1995). If seeding is an option, drop 4-5 under mulch every 30-40 feet, preferably on a cloudy wet cool day. In one case, a farmer used an earth auger attached to a cordless drill and put a handful of worms per hole every 30 feet (Ernst, 1995). Even with seeding, however, populations will still take five years or more to grow significantly, if they survive at all (Kladivko, personal communication.)

The Netherlands has reported the addition of earthworms on once flooded soils that have been drained (polder soils). Natural earthworm densities have increased over 26 years following reclamation. However, much higher population densities have been found where earthworms were seeded (Edwards and Bohlen, 1996).

Summary

Earthworms benefit soil quality by shredding residues stimulating microbial decomposition, improving soil fertility, and improving soil physical properties such as soil aggregation and infiltration. Food availability is the major factor limiting earthworm numbers. Producing food through crop residues and cover crops and leaving them on the soil surface through the use of conservation tillage practices provides food to increase earthworm numbers. Generally, fertilizers increase earthworm numbers by increasing crop residues, especially when pH is maintained near neutral. Herbicides are generally harmless to earthworms. However, some insecticides, nematicides, fungicides are very toxic to earthworms. In some situations, earthworm inoculation may be desirable to introduce certain species to an area once earthworm friendly practices are in place.

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