



Earthworms – Architects of fertile soils

Their significance and recommendations for their promotion in agriculture

In Brief

Today, much is known about the general taxonomy and biology of earthworms, whereas relatively little is known about their impact on soils, their interactions with other soil organisms and the influence of farming practices on their populations.

This guide gives a brief overview of the biology, ecology and the multiple services of earthworms to farmers and provides recommendations for the promotion of these extraordinary creatures in agricultural soils.



Underestimated workers

In the 19th century earthworms were considered a soil pest. Even though this view has changed, earthworms receive little attention in agricultural practice. Very few farmers only actively promote them. Increasingly heavy machines, intensive tillage and intensive use of pesticides have in many places eliminated earthworms in fields. In contrast to this scenario, in the healthy soil of one hectare of grassland one to three million earthworms can be found.

Number and diversity of earthworms in a soil are considered an important criterion of soil fertility, because earthworms contribute in many ways to healthy and biologically active soils and better adaptation of farming systems to climate change, thus providing key soil functions that favour many positive ecosystem services. Due to their numerous services that increase sustainability of agro-ecosystems, earthworms should receive more attention in sustainable farming systems.

Distribution and biology

With the exception of the Polar Regions and deserts, earthworms can be found in most soils. While more than 3.000 species are known worldwide, only 400 species are found in Europe and 40 species in Central Europe. In cropland only 4 to 11 species are commonly found.

Earthworms prefer medium-heavy loam to loamy sand soils. Heavy clay and dry sandy soils are not favourable to their development. In acidic peat soils only specialised species are found that have adapted to such "hostile-to-life" conditions.

Earthworms are hermaphrodites and develop slowly, with the exception of the leaf litter dwellers. Only one generation with a maximum of 8 to 12 cocoons (eggs) is produced per year. Earthworms live 2 to 8 years, depending on the species. Sexually mature worms can be identified by the "genital belt" (clitellum) encircling the body.

Peak burrowing activity and reproduction take place in March and April and also in September and October (temperate zone). When it is very dry and hot, many earthworms estivate and retreat to deeper

soil layers. In the cold of winter the worms retreat to frost-free portions of their burrows, and their metabolism slows down to the minimum. During frost-free winter days they become active again. Earthworms can migrate into cropland from undisturbed edge areas like field margins. The night crawler (*Lumbricus terrestris*) can migrate as far as 20 metres per year.



A *Nicodrilus* sp. curls up to survive cold, hot or drought periods and during hibernation or estivation.

Nutrition

Earthworms primarily feed on dead plant parts. At night they graze on the lawns of algae that have grown on the soil surface during the day and pull dead plant parts into their burrows for "pre-digestion" by soil microorganisms in 2 to 4 weeks. Earthworms lack teeth and therefore cannot feed on roots. In order for earthworms to thrive, a rich food supply is essential.

Impact of common agricultural practices on earthworm populations

Application of pesticides can affect earthworms in three ways: i) They can affect their gene-expression and physiology (intra-individual level), ii) change life history traits, population density and behaviour (individual and population level) or iii) modify biomass and density of earthworm populations (community level). Pesticides may disrupt enzymatic processes, increase individual mortality, decrease fecundity and growth, or they may change individual behaviour such as feeding rate and decrease overall community biomass and density.

Anectic earthworms such as *L. terrestris* are most susceptible to surface application of pesticides. Because *L. terrestris* forms permanent burrows, it does not come into contact with subsurface soil in its burrows. In contrary, endogeic species such as *A. caliginosa*, which continuously extend their burrows as they feed in the subsurface soil, are most susceptible when toxic pesticides are incorporated into the soil.

Most herbicides probably do not damage earthworms directly. If herbicides are applied at recommended rates of use, they tend to have low toxicity for earthworms. But they can reduce earthworm populations by decreasing availability of organic matter on the soil surface from weed plants.

Some inorganic fertilizers, especially ammonium sulfate, can be harmful to earthworm populations, possibly due to an acidifying affect.

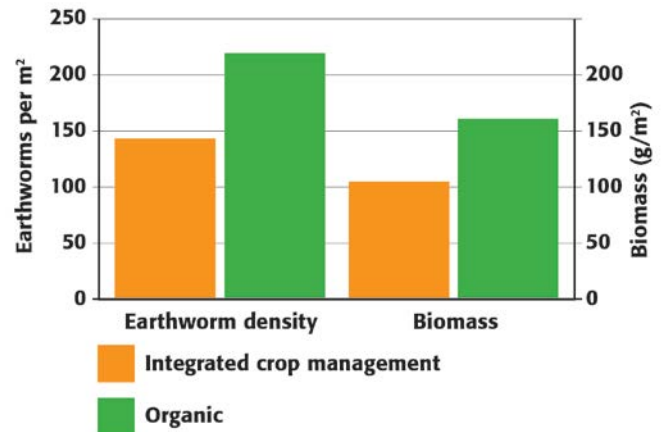


Figure 1: Significant impact of arable farming systems on earthworm density and earthworm biomass in cereal fields (Piffner & Luka 2007).

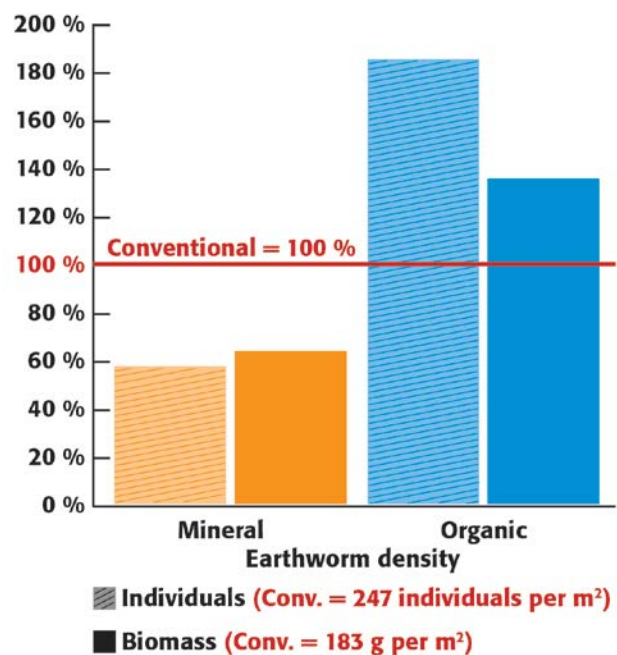



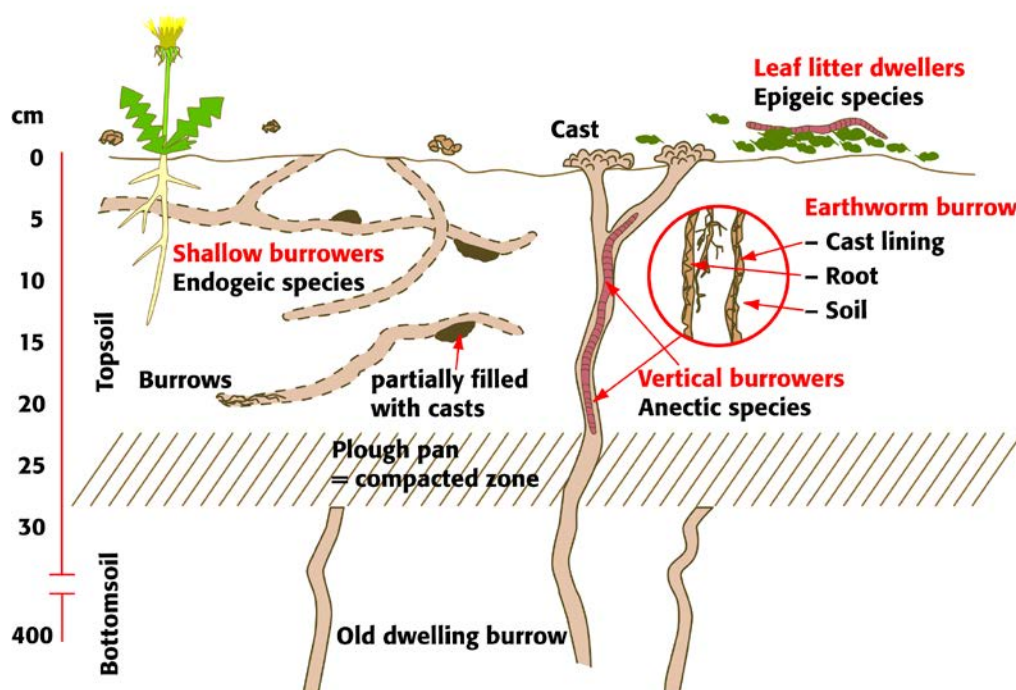


Figure 2: Effect of fertilization and pesticides in different farming systems on the number and the biomass of earthworms (average from three years) in a long-term trial (DOK trial). Mineral = purely mineral fertilization and integrated pest management; Conv = mixed mineral and organic fertilization and IPM; Organic = use of fresh manure only and no use of chemical pesticides. (Piffner & Mäder 1997).

Three ecophysiological categories of earthworms in temperate ecosystems

Groups	Leaf litter dwellers	Shallow burrowers	Deep burrowers
	Surface dwellers, epigeic species	Shallow burrowing, endogeic species, horizontal burrowers	Vertically burrowing, anectic species
Representatives			
Examples	<ul style="list-style-type: none"> ➤ Redworm (<i>Eisenia fetida</i>) ➤ European earthworm (<i>Lumbricus rubellus</i>) 	<ul style="list-style-type: none"> ➤ <i>Octolasion lacteum</i> ➤ Common field worm (<i>Allolobophora caliginosa</i>) 	<ul style="list-style-type: none"> ➤ Nightcrawler (<i>Lumbricus terrestris</i>) ➤ Black-headed worm (<i>Allolobophora longa</i>)
Colour	Brownish-red overall	Pale	Reddish-brown, head darker
Habitat	<ul style="list-style-type: none"> ➤ In litter layers, especially in grasslands, forests, and compost ➤ Rarely found in cropland due to lack of permanent litter layers 	<ul style="list-style-type: none"> ➤ Topsoil (5–40 cm), humic mineral soil ➤ Mostly horizontal, unstable burrows ➤ Juveniles are generally found in the upper layers in the tangle of roots 	<ul style="list-style-type: none"> ➤ All soil layers, 3–4 m deep ➤ Spend their entire lives in vertical, stable dwelling tubes (Ø 8–11 mm) ➤ Important in agricultural soils
Size	Small, generally 2–6 cm long	Small to up to 18 cm long	Generally large, 15–45 cm long
Feeding behavior	<ul style="list-style-type: none"> ➤ Feed on small plant parts on the surface of the soil 	<ul style="list-style-type: none"> ➤ Feed on plant parts incorporated in the topsoil 	<ul style="list-style-type: none"> ➤ Pull large plant parts into their dwelling tubes
Reproduction	<ul style="list-style-type: none"> ➤ Vigorous ➤ 100 cocoons per year 	<ul style="list-style-type: none"> ➤ Limited ➤ 8–12 cocoons per year 	<ul style="list-style-type: none"> ➤ Limited ➤ 8–12 cocoons per year
Lifespan	Short, 1–2 years	Medium, 3–5 years	Long, 4–8 years
Sensitivity to light	Weak	High	Moderate



The three ecophysiological categories of earthworms have distinctly different feeding and living habits.

How do earthworms benefit soil fertility?

Earthworms annually deposit up to 10 kilos per square metre of valuable worm droppings in the soil and on its surface. This is as much as 0.5 cm of the soil layer in fields, and as much as 1.5 cm in meadows. But beyond this earthworms provide many more services to the soil, too.



Earthworm burrows are lined with worm casts, brown traces of humus and white spots of crystallized nutrients, providing excellent growing conditions for plant roots.

1. Earthworms aerate the soil

Earthworm burrows ensure that the soil is well-aerated and increase the amount of macro-pores.

2. Earthworms improve water infiltration into soils and reduce surface runoff

The stable burrows of the vertical burrowers in particular considerably improve water infiltration, storage and drainage of soils. Surface runoff and erosion are thus reduced. Up to 150 burrows, or 900 metres of burrows per square metre and metre of depth, can be found in unploughed soil. The vertical burrows stabilized with slime can be as deep as 3 metres in deep loess soils, and even as deep as 6 metres in chernozem soils ('Black earths'). Due to their powerful muscles, deep burrowers are able to penetrate slightly compacted soils and thus improve drainage.

3. Earthworms decompose dead plant matter

In fields, earthworms incorporate up to 6 tons of dead organic matter per hectare per year into the soil. In forests, earthworms process as much as 9 tons of foliage per hectare.

4. Earthworms concentrate plant nutrients

Earthworms produce 40 to 100 tons of casts per hectare annually. The worm casts form stable soil aggregates (crumbs), which are deposited on the soil surface. Organic and inorganic fractions are well-mixed in worm casts, and the nutrients are present in a readily available and enriched form. The casts contain on average 5 times as much nitrogen, 7 times as much phosphorus, and 11 times as much potassium as the surrounding soil.



This soil has many worm casts on the surface indicating high earthworm activity. It hardly becomes muddy after heavy rains. Picture taken from an organically managed plot of the DOK long-term trial in Therwil, Switzerland.



Worm casts are largely lacking on this soil surface indicating little earthworm activity. During heavy rains the soil surface tends to silt up. Picture taken from a conventionally managed plot of the DOK long-term trial in Therwil, Switzerland.

5. Earthworms rejuvenate the soil

Earthworms transport soil material and nutrients from the subsoil to the topsoil and thus maintain the vitality of the soil.

6. Earthworms act as biocontrol propagators

Earthworms promote the colonization and propagation of beneficial soil bacteria and fungi in their burrows and casts. By pulling fallen leaves into the soil, foliar pathogens and pests (winter stages of fungal pathogens such as apple scab, and insects such as leafminers) are biologically degraded. Dormant forms (spores), however, resist digestion in the earthworm gut and are excreted in casts.

7. Earthworms promote root growth

Over 90 % of the burrows tend to be colonized by roots. Roots are thus able to penetrate into deeper soil layers without meeting resistance, finding nutrient-rich earthworm casts, water and air.



The burrows made by deep-burrowing earthworms make it easier for roots to penetrate deep into the soil.

8. Earthworms promote the formation of soil structure and soil stability

By the intensive mixing of organic matter with inorganic soil particles and microorganisms and by slime secretion, earthworms create stable soil crumbs, which contribute to a good soil structure. Soils with high earthworm activity have less tendency to become muddy and can be worked more easily

than soils with low earthworm activity. In addition, nutrients and water are more effectively retained in the soil. Abundant worm casts production makes heavy soils looser and sandy soils more cohesive.



The worm casts form stable soil aggregates and are rich in nutrients. Earthworms may produce 40 to 100 tons of casts per hectare annually.

Earthworms help control soil-borne pests

Recent studies show that earthworms promote the growth and propagation of beneficial organisms in the soil. Earthworms distribute insect-killing nematodes (*Steinernema* sp.) and fungi (*Beauveria bassiana*) in the soil, thus contributing to better natural regulation of soil-borne pests. Fungus spores survive passage through the earthworm gut and reproduce afterwards in earthworm droppings. Vertical-burrowing species such as the nightcrawler or the black-headed worm, which construct permanent dwelling burrows, perform valuable services in this regard.

9. Earthworms and carbon sequestration

Earthworms ingest organic residues of different C:N ratios and convert it to a lower C:N ratio and finally contribute to carbon sequestration. Thus they help also to mitigate climate change.



Earthworms pull fallen leaves into the soil quickening the degradation of foliar pathogens and pests such as apple scab and leafminers.

Effective agricultural practices to enhance earthworms

Avoiding intensive soil tillage and minimizing the use of the plough

- Ploughs and fast-rotating devices should only be used, if absolutely necessary, as they can greatly damage earthworms at certain times of the year. Loss rates of earthworms after the use of ploughs are about 25 %, and can be as high as 70 % after the use of rotary devices (see figures below).
- Intensive soil tillage should be avoided during the periods of high earthworm activity in March/April and September/October.
- Tillage of dry or cold soils has much lower negative impacts on earthworm populations, as the majority of the earthworms have retreated to lower soil layers during such periods.
- The use of on-land ploughs and shallow ploughing reduces compaction of deeper soil layers.
- Conservation tillage, which includes reduced tillage, minimizes soil disturbance reducing the risk of soil compaction, maintaining proper water infiltration, reducing water run-off and evaporation, and thus improving water storage.

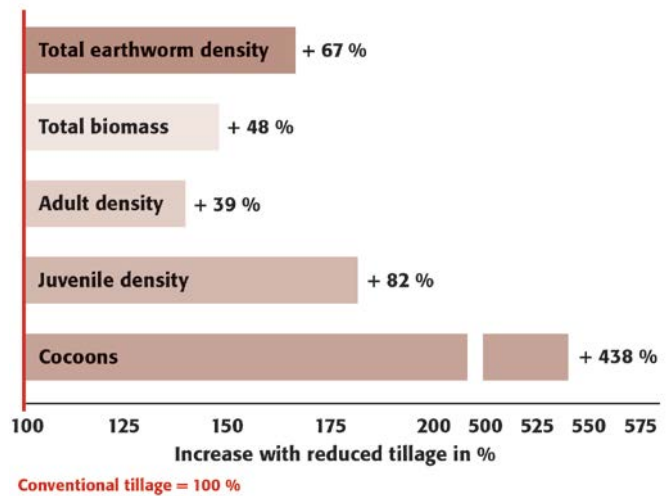
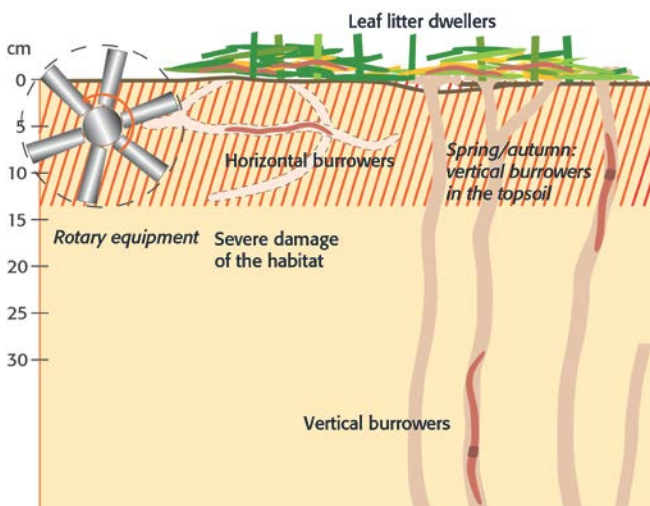


Figure 3: Impact of reduced tillage compared to ploughing (conventional tillage = 100 %) on earthworms in an organically managed clay soil. Relative increases of earthworm population density, biomass and growth stages compared to ploughing (Kuntz et al. 2013).

Impact of different intensities of tillage on earthworms

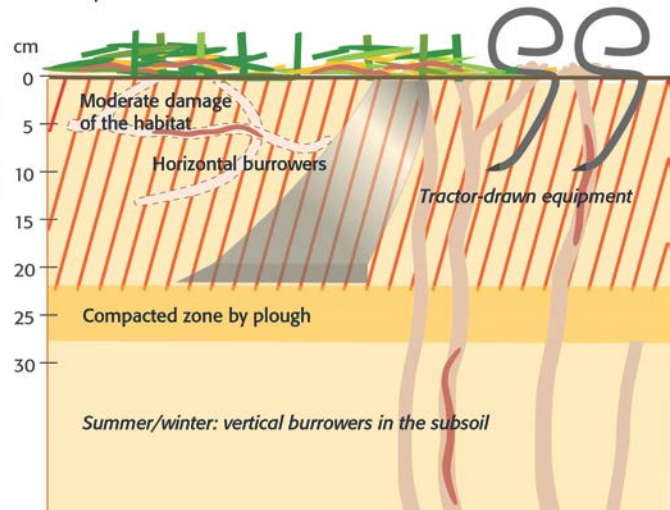
Intensive soil tillage

Up to ca. 70 % earthworm losses



Medium-intensive soil tillage

Up to ca. 25 % earthworm losses



The more intensively the soil is cultivated, the greater the losses. Losses are highest in spring and autumn.

Minimizing ground pressure and soil compaction

- › Compaction of the soil has negative impacts on earthworm populations and other organisms. The heavier the equipment, the greater the compaction of the soil.
- › Machinery should be adapted to keep ground pressure to a minimum (tyre pressure, weight of machinery).
- › To avoid soil compaction, only well-dried, good bearing soils should be cultivated.



The on-land plough helps prevent soil compaction in the plough pan.



Lighter till and drill combinations spare earthworms.

Diversifying crop rotation to enrich the menu of earthworms

- › A diversified crop rotation with long-lasting and deep-rooted catch crops rich in clover or green manure crops, and diversified crop residues are the basis for rich soil life and essential to maintain or increase earthworm populations.
- › A continuous cover of plant residues or vegetation on the soil (especially over the winter) is very beneficial to earthworms and other soil fauna.
- › Perennial clover-grass meadows regenerate earthworm populations substantially and are more beneficial than a 1-year grass ley.

Fertilizing in relation to soil properties and plant needs

The type and the amount of fertilizer used both affect earthworm populations.

- › A soil, which is fertilized adequately to the crop needs and in a well-balanced manner, is good for both crops and earthworms.
- › Slightly-rotted composted manure contains more food for earthworms and, thus, is better suited to promote earthworms than ripe compost.
- › Organic fertilizers should only be incorporated to a shallow depth. Deeply buried crop residues are detrimental to earthworms, because anaerobic conditions can occur.
- › As the ammonia in unprocessed liquid manure is very harmful, especially to earthworms living near the surface in waterlogged soils, liquid manure should be stirred (and thus aerated) and diluted prior to application.
- › Liquid manure should be applied to absorbent soils only and in moderate amounts of about 25 m³ per hectare.
- › To ensure neutral soil pH (H₂O) lime should be applied routinely on the basis of pH measurements. Soil pH (H₂O) below 5.5 is harmful to earthworms.



When diluted and applied in moderate amounts at the right time, liquid manure is beneficial for earthworms and crop growth.



A rich earthworm fauna helps cut down silting up and improves water infiltration and storage.

Estimation of the number of earthworms in a soil

In Central Europe 120 to 140 worms per square metre make a good population density for cropland.

The approximate number of worms can be roughly estimated using the following methods, which can be easily used by practitioners:

- A 10 x 10 cm and 25 cm deep spade full of fertile, medium-heavy loam soil contains in average 2 to 3 worms. This amount corresponds to 100 to 200 worms per square metre.
- The number of worm burrows is also a good indicator of worm activity in the soil.
- When counting the number of casts (worm droppings) on a 50 x 50 cm area during the periods of earthworm activity (March to April and September to October) i) 5 or fewer casts indicate little worm activity, ii) 10 casts indicate moderate worm activity, whereas iii) 20 or more casts indicate good worm activity with the soil containing many worms.



An earthworm emerges from a cocoon.

Habitat affects earthworm density

The colonization of a habitat by earthworms primarily depends upon food and water supply. Accordingly, there is considerable variation in the number of earthworms per square metre:

Low-input pasture	400–500 earthworms
Fertilized meadow	200–300 earthworms
Hardwood forest	150–250 earthworms
Low-input arable field	120–250 earthworms
Poor grassland	30–40 earthworms
Spruce forest	10–15 earthworms



Only mature specimen with a clitellum can be clearly determined to a species level (e.g. *Eisenia foetida*).

Summary: key measures for the promotion of earthworms

The following measures are pre-requisites for the flourishing of earthworms in agricultural soils:

1. Provision of sufficient food (plant material) to earthworms
2. Abstaining from the use of pesticides harmful to earthworms
3. Application of soil-conservation methods such as reduced tillage and no-till
4. Avoidance of soil compaction and promotion of well-structured and aerated soils
5. Site and crop appropriate fertilization, balanced humus management within the crop rotation

A rich earthworm fauna is a key to maintain and safeguard soil health and to foster many essential ecosystem functions of soils.

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