

## ***Between a Rock and a Hard Place***

***Does maximizing soil biodiversity increase crop productivity?***

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The pile of weathered rocks and decaying debris that we call soil is home to a rich community of living organisms. The structure and nature of the biological community that resides in and on the soil is influenced by management practices such as amendment application and tillage. It's important to manage this community to provide an array of functions and improve productivity

However, this doesn't mean farmers must maximize organism diversity to a broad degree. Many species perform similar tasks, so it's only necessary to encourage those already adapted to a given location. What's nice is that each field or farm doesn't need the exact same set.

We know soil productivity is unsustainable without a strong biological component, but just how many different organisms are necessary? These organisms— protozoa, mites, nematodes, fungi, and bacteria— along with macrofauna such as earthworms, directly influence the quality, structure, and fertility of soil. This interdependent biological community develops soil structure, or tilth, from disconnected sand, silt, and clay particles while transforming organic material into available nutrients.

Good, productive soils highlight three functions of a balanced soil community: 1— energy flow and nutrient cycling, 2— formation and maintenance of soil structure, and 3— pathogen control.

### **Form versus function**

Most people define biodiversity as the number of unique species found in a given area. However, another approach lumps these organisms together based on the specific function performed.

To evaluate energy flow and nutrient cycling within an ecosystem, it makes sense to group organisms in terms of their trophic level. Trophic level describes an organism's position in the food chain. For example, a simple meadow food chain is plant → mouse → hawk/coyote. Hawks and coyotes are predators at a similar trophic level even though, as individual organisms, they are strikingly different.

### **Gobblers, shredders, and earthmovers**

In the soil, we define the relevant trophic groups as primary, secondary, and higher level consumers. Primary consumers are those capable of breaking down organic material at the molecular level. They do this by exuding enzymes that literally break the bonds holding dead plant and animal materials together. Just like hawks and coyotes, primary consumers such as single-celled bacteria and multi-cellular fungi are quite different from one another, albeit performing the same job in the soil. In addition to multiple functions, soil organisms also span body sizes from a miniscule <0.001mm up to 50mm. Based on size, secondary consumers like protozoa, nematodes, springtails, and mites affect soil at radically different scales.

Bacterial-feeding nematodes and protozoa gobble up bacteria, and then excrete ammonia and other nutrients. Springtails and fungal-feeding nematodes digest fungal mycelia, making nutrients available. Mites, springtails, and other arthropods feed directly on organic material,

converting it into fecal pellets and smaller, more degradable pieces of organic matter. These are the largest members of the secondary consumer group often referred to as litter transformers or shredders.

Earthworms, ants, and termites are the heavy machinery operators of the soil community and have a direct effect on soil structure. Worms have an ulterior motive for their incessant movement through the soil— their need for the perfect environment. More suited for aquatic than terrestrial life, earthworms need a precise amount of moisture in the soil surrounding them.

While many organisms have kidneys to cleanse internal fluids and excrete a concentrated waste product, earthworms produce large amounts of dilute urine, using water in the surrounding soil almost as an accessory kidney. However, this only works after the worm alters, or engineers the soil to suit.<sup>1</sup>

Earthworms move up and down through the soil searching for specific water pressure. Their engineering efforts introduce structure to the soil; macropores are formed, soil particles are physically pushed together to form aggregates, and earthworm castings become large particles (aggregates) resistant to erosion.

### Land rush

Another important function is the control or prevention of disease. Healthy soil communities use competition as well as predation to control plant pathogens. Since there is always a limit to resources and space in any soil, organisms use different strategies to grab as much as they can of what's available. This may include growing through a substrate (food source, such as plant debris) quickly, colonizing a specific substrate difficult for others to digest, or by excreting compounds other organisms cannot tolerate. Many antibiotics used today were first discovered in soil microbes.

On the other hand, plant pathogens survive by finding and infecting a host. In the absence of a host, they must either wait for one to come along, colonize organic material, or go dormant. In any case, they are in direct competition for space and resources with other, usually stronger, competitors.

Occasionally, some fungi directly attack other fungi, including pathogens. However, predatory control of soil pathogens is not nearly as common as control via competition.

Soil group	Body width (mm)	Functions	Susceptibility to disturbance
Macroarthropods (millipedes, isopods)	2-20	Shredders	High
Earthworms	2-20	Ecosystem engineers	↑ ↓
Microarthropods (springtails, mites)	0.07-2	Fungal feeders, shredders	
Protozoa	0.08-0.1	Bacterial feeders	
Nematodes	0.003-0.1	Bacterial/fungal feeders; nematode/protozoa predators; plant pathogens, omnivores	
Fungi	0.001-0.003	Primary consumers; general and specific biocontrol	
Bacteria	0.00001-0.001	Primary consumers; general and specific biocontrol	

### Many hands make light work

Using a common example, mice are a great food source for a variety of predators. If the neighborhood hawk disappears, chances are the neighborhood cats will quickly fill the void by eating a little more richly for a time. Most often, the loss of a single predator species will not result in a mouse takeover.

However, if the cats disappear as well and there are no other predators available to take up the slack, conditions are prime for a mouse population boom. Scientists refer to the ability of an

ecosystem to resist change—in this case a mouse explosion—as its resilience. The variety of organisms available in a given system doing the same job is referred to as redundancy. In most soils, there's a high degree of redundancy among both primary and secondary consumers. Instead, limitations for primary consumers include the type of organic matter, moisture availability and, to some extent, the degree of soil disturbance.

Nitrogen-rich organic matter favors organisms capable of rapid exploitation often leading to population explosions of bacteria and bacteria-feeding animals. Organic material with lower concentrations of nitrogen favors fungal colonization. Drier, more stable conditions such as no-till systems favor fungi as well. With the huge variety of decomposer species in existence, lack of diversity rarely limits their role in soil productivity. However, some organic materials such as lignin-rich bark or waxy leaves require specific fungal species for nutrient cycling. If they aren't already present, nutrient cycling will be slow until the right ones show up in sufficient numbers.

### **Feed me**

While adding fresh organic material may result in a short-term bloom of bacteria, fungi tend to dominate these jobsites. There is a direct link between the amount of material available and the number of fungi working hard to devour and process it. This direct link between food and feeder is referred to as “bottom up” control.

Unlike fungi, bacterial populations are often limited, not by a lack of food but by predation or “top down” control. Predators like nematodes prefer eating bacteria to fungi because they contain higher concentrations of nitrogen and phosphorus.

Secondary consumers—protozoa, nematodes, springtails, and mites—cover a large size range (see table) and as a result have a broad effect. Studies that intentionally eliminate larger-bodied organisms such as springtails and mites show a decrease in nutrient cycling compared to similar settings where they are present. Disturbances such as tillage can kill off large numbers of these creatures. Luckily, they are quick to re-colonize, helping make nutrient cycling robust and resistant to change.

### **Chink in the armor**

Ecosystem engineers like earthworms are some of the largest organisms inhabiting soil. In spite of their tough, heavy equipment operator role, they are more sensitive to soil disturbances than many smaller organisms. Studies show populations increase and stabilize when disturbances such as tillage are reduced.<sup>2</sup>

Unfortunately smaller organisms cannot perform the large-scale earth-moving necessary for optimal productivity, so this crucial role is solely dependent on conditions favorable to earthworms— minimum disturbance and optimum moisture levels.

### **Feed a cold, feed a fever**

Competition is most effective as a pathogen control when resources are relatively scarce. Adding manure or compost can result in a bloom of microbial activity. Regrettably, some pathogens also bloom with the addition of organic material.

Timing planting becomes crucial to prevent problems. Planting too soon after adding amendments can result in expanding pathogen populations with damping off a likely result. However, after initial bloom subsides and resources wane, competition between the good and bad bugs starts to heat up, with the good bugs most often winning.

### **Patience is a virtue**

Without abundant resources, pathogens are not nearly as competitive as non-pathogens. When resource levels dip, populations drop and threats against seedlings reduces as well. Dr. Harry Hoitink, plant pathology professor emeritus at Ohio State University, recommends waiting at least two weeks after adding compost before planting for maximum pathogen control.<sup>3</sup>

Studies demonstrate many non-pathogenic soil organisms have this competitive edge, so greater biodiversity is not an important factor and will not necessarily increase competition.

### **Right bug, right place**

The presence of a unique non-pathogen is more important for suppressing pathogens that colonize dead organic matter. In this case, having greater biodiversity increases the chances of having the right species available, helping make the soil what is termed “suppressive.”

For example, in wheat fields a specific beneficial organism causes something called “take-all decline.” This occurs in soils where wheat is grown for several years without rotation resulting in a severe out-break of take-all disease. Oddly enough, after a few years of severe crop loss, population levels crash to a manageable level and yields increase to almost pre-disease levels, a direct result of the ‘right’ bug having found the field and eventually colonizing in sufficient numbers.

### **You can take it with you**

One key aspect to suppressive soils is that this function is transferable. In a greenhouse experiment, a known suppressive soil was mixed with a pathogen-laden soil. Over time, the entire mix became suppressive after the needed organism multiplied to adequate levels. While there is no dispute this phenomenon is biological, it’s also acknowledged that different organisms are responsible for the suppressive factor in different areas.

In the Palouse, *Pseudomonas* bacteria produce an antibiotic associated with the suppression of take-all decline.<sup>4</sup> While a marketable product to ‘seed’ *Pseudomonas* is not currently available, other products are available that attack other plant pathogens. Research and development of these products is continuing and a list of currently products is available from ATTRA.<sup>5</sup>

### **Putting it all together**

Because of the many connections between physical, chemical, and biological soil properties, simply maximizing biodiversity is not the key to increased productivity. While a buffet table of species can cycle nutrients and out-compete pathogens, only a few need be present for maximum effectiveness. They are usually robust and rarely bothered by tillage practices, but are more dependent on amendments and the passage of time for optimal function.

On the other hand, broad biodiversity is needed for functions such as soil engineering and attack-type pathogen control. To encourage the unique individuals needed, minimal disturbance and even inoculation may be necessary.

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