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Perspectives

How to cite:

Winiwarter, Verena. "The View from Below: On Energy in Soils (and Food)." In: "Energy Transitions in History," edited by Richard W. Unger, *RCC Perspectives* 2013, no. 2, 43–48.

All issues of *RCC Perspectives* are available online. To view past issues, and to learn more about the Rachel Carson Center for Environment and Society, please visit www.rachelcarsoncenter.de.

Rachel Carson Center for Environment and Society
Leopoldstrasse 11a, 80802 Munich, GERMANY

ISSN 2190-8087

SPONSORED BY THE

Federal Ministry of Education and Research

Deutsches Museum

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Verena Winiwarter

The View from Below: On Energy in Soils (and Food)

Pre-modern agriculture is commonly described as suffering from a paucity of nutrients. The paucity in nutrients is a consequence of energy scarcity. Energy scarcity was a standard feature of pre-modern agricultural operations, so using one's energy well was critical. Some energy had to be spent tilling and improving the soil, work for which return on investment came only after several growing seasons. Agricultural manuals make a case for such work, as they regard effort targeted at soil ecosystems below the surface, as yet unseen and largely unknown, to be of the utmost importance.

Photosynthesis, likewise unknown as a concept in pre-modern agriculture, provides the basis of all agricultural operations. To keep plants growing, their energy-creating machinery has to be kept running; for that, plant nutrients are necessary. Energy investment in manuring, fertilizing, plowing, harrowing, marling, and other operations with the soil was and is necessary to obtain food.

Charles Darwin considered his 1881 book *The Formation of Vegetable Mould through the Action of Worms with Observations on their Habits* as more important than his evolutionary work. The origins of the book go back to his paper "On the Formation of Mould," read 1 November 1837 and published in the following year in the *Proceedings of the Geological Society of London.* Darwin had investigated a phenomenon nowadays called "bioturbation," the mixing of soil by the action of soil organisms. Considerable energy is spent by those organisms, whose metabolic output as they digest earth is central to mold formation. Worms are very important farm workers.

Earthworms and other soil biota create, by means of their metabolism, the niche in which they thrive—the humus-rich, loose soil with lots of nutrient minerals that agriculturalists find the most productive for rearing plants. Therefore, niche construction should be incorporated into an understanding of agriculture. One can describe agriculture as a human effort of cultural niche creation, but it can also be seen as worms domesticating humans to co-create their niche. In their 2003 overview of the biological principle of niche construction, biologists Odling-Smee, Laland, and Feldman use earthworms as an example of their concept. The worms burrow, drag organic material into the soil, mix it up with inorganic material, and cast the digested material; all of this serves as the basis for microbial activity. Earthworms dramatically change the structure and chemistry of the soils they live in, creating niches. In temperate grasslands earthworms can consume up to 90 tons of soil per hectare per year. Earthworms also contribute to soil genesis, to the stability of soil aggregates, to soil porosity, to soil aeration, and to soil drainage. Because their casts contain more organic carbon, nitrogen, and polysaccharides than the soil they ingest, earthworms affect plant growth by ensuring the rapid recycling of many plant nutrients. In return, the earthworms probably benefit from the extra plant growth they induce by gaining an enhanced supply of plant litter. All of these effects typically depend on multiple generations of earthworm niche construction, leading only gradually to cumulative improvements in the soil.

Manure has important consequences for earthworm habitat. It increases the amount of soil organic matter (SOM) as well as raising the pH of the soil, which makes biological activity shift from slow, fungi-dominated processes to faster, bacteria-dominated processes. Under the predominance of bacteria, the rate of mineralization caused by microbial decomposition of organic matter is increased. The water-holding capacity of the soil is increased, as are its hydraulic conductivity and infiltration rate. Nitrogen, phosphorus, and potassium are added while the bulk density is decreased. Recalcitrant components of manure form a reserve pool of nutrients for mineralization. In short, most of the characteristics of soil are profoundly changed by manuring, providing a different habitat for the subterranean workforce.

Applying Laland, Odling-Smee, and Feldman's work to soil ecosystems, we can say that earthworms create the ecological niche that humans consider man-made, an agro-ecological niche. But life on the farm is best understood in an even more dialectical way. From the niche-construction perspective, evolution is based on cycles of causation and feedback. Organisms drive environmental change and organism-modified environments subsequently select organisms. Nest-building generates selection for nest elaboration, defense, and regulation. Niche construction is not just an end product of evolution, but a cause of evolutionary change.

To explain this, Odling-Smee introduced the notion of ecological heritage in 1988. Biology has long turned away from the idea of a habitat as a fixed set of environmental parameters, and has come to understand niches, the places of a population in an environment, as the product of interactions among the organisms forming the niche. The niche of an animal reflects its role in a community: eating its prey, being eaten by its hunters, occupying a place in a habitat. When ecologists talk of a "niche" they talk about the animal's role rather than "where" the animal can be found. A species' characteristic ways of living can include making lasting changes made to their environments. Such changes have effects beyond the lifespan of the generation responsible for the changes. An ecological inheritance is the result. Niche construction is a very common phenomenon, with dens and burrows being good examples of the heritable parts of a niche. Such constructed niches can be quite permanent structures, used (and changed) by several generations of inhabitants. This means that the purposive intervention of the species leads to a change in the local environment, which then acts as a selective force for future generations. Not only the environmental conditions as such but also the ecological inheritance, for example the burrow, are a means of natural selection. Humans construct their ecological niche by building their type of dens (houses) and by altering natural systems through colonizing interventions. The lasting changes they make act as means of natural selection on them. One such example is provided by zoonoses, diseases which crossed from animal hosts to humans as a result of the close contact between humans and their domesticated animals.

Another such example is provided by agricultural soils. Agriculture usually takes place on soils left by one generation of humans for the next. The ecological inheritance in this process is not small. Soils bear a lasting, discernible mark of previous cultivation, leaving a particular ecological inheritance. Some amendments are particularly long-lasting. The most common of these is marl.

The use of this mixture of clay and calcium carbonate is recorded as early as the ninth century, and evidence for continued reliance on marl to improve soil fertility runs in the nineteenth century. Various sources, such as farmers' diaries and recommendations to farmers from experts, indicate widespread knowledge of the benefits of using marl.

Gathering, storing, hauling, and spreading manure was part of the huge internal material flows on the farm necessary to keep it productive. These material flows matter. Manpower is crucial to the maintenance of soil fertility. The use of marl is an obvious example. As effects cannot always be noticed quickly, with yields varying from year to year, the more immediate needs determine where farm work is allocated. That meant that in some cases farmers ignored the need for marling and did not enjoy the benefits. Nineteenth-century agronomists were often enthusiastic about the fertilizing properties of marl. Government officials chimed in with recommendations for improving soil fertility through the addition of marl.

The history of marl use and the strong support for its application illustrates the need for a history that considers energy and coevolution. The concept of an ideal farm as laid out by Arthur Young in 1770 helps to illustrate the implications of the distribution of farm labor and manuring for human history. Young suggested that the farm should be "proportioned" so that all labor and soil fertility maintenance needs could be met. This was to be achieved at considerable expense, mainly because it entailed keeping farm animals and keeping them at work.

Labor expenditure for maintaining the subterranean niche went beyond hauling. Young criticized the practice of using unprepared manure and described the work entailed in preparing it. Valuable ditch-earth was also left unused, Young noted. Similarly, he was concerned with the failure of agriculturalists to exploit the potential contribution of the night soil of the townspeople to soil fertility. He was convinced that a small farm could not be as profitable as his model farm, an important reason being the neglect of niche construction work by farmers busy with their short-term work.

The model farm would run into a dilemma, or, to put it more in economists' terms, into a problem of optimization. Feeding the animals whose excrement is needed to feed the soil biota is expensive. As Young's account is detailed, it is easy to assess, through his listings and calculations, the overall labor investment that an ideally proportioned farm would have had to make in soil-habitat management. Hauling marl and manure were crucial to success. But that in turn entailed keeping carts and teams of oxen or horses, digging marl pits, and making a big investment in infrastructure. Cattle, for example, would have to be kept in stables, which needed to be cleaned regularly.

We can calculate that 18 percent of the labor cost on the model farm came from manuring. 12–25 percent of feed for draft animals went into manuring. Additional expenses were incurred in buying and hauling straw, stubble, night soil, and so on. A rough estimate would be that 20 percent of all operations on Young's model farm were directly related to manuring.

This means that nutrient management was under severe labor constraints in pre-modern agriculture. While the manuals make clear that farm operators understood that they should invest in manuring, it was costly to do so. And as poorer farmers did not have the means to buy enough cattle even to convert their own straw into manure, there was also a capital limitation on soil biota management, with potential long-term effects on soil quality. The soil quality would eventually decline on such farms that were too small and poor to allow them to sustain it, bringing the smallholders into a downward spiral of declining yields. That not all smallholders were doomed has been pointed out by Robert McC. Netting, but the sustainable systems he describes are labor-intensive, almost horticultural in their nature. They develop ingenious methods, such as using fish ponds as nutrient pools, but they can easily be disturbed and brought to ruin, as their niche construction is fragile.

The energy investment in soil fertility is considerable. It might be as high as a quarter of the labor cost of a farm and its capital ramifications are significant. The energy investment goes into the provision of nutrients and into habitat improvement for the subterranean workforce of earthworms on which agriculture depends. It is a matter of perspective whether humans are providing a niche for those soil biota that produce plant nutrients as their excreta, or whether earthworms are providing humans with a niche in return for feeding them. Earthworms could argue that they domesticated humans to feed them. Nutrients and energy are closely intertwined and should be seen as two sides of the same coin rather than as two different constraints of agricultural success.

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