ENVIRONMENTAL HISTORY OF SOILS

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Contents

Summary

Soils are complex ecosystems. They are the basis of human sustenance and have been changed by humans for millennia. Their environmental history needs to be built on pedological, historical and archeological data. A primer on important concepts of soil science introduces the complexity of soils and their interactions with humans.

Many societies developed soil classification systems, testing methods for soil quality and a multitude of measures for soil fertility maintenance. They also developed landscaping techniques such as terracing to enhance the utility of their soils. In a comparative approach, these three fields of soil knowledge and their development during pre-industrial times are discussed for the history of China, Mexico, Mesoamerica and Amazonia as well as for India. Ghana and the Nile valley serve as two examples from Africa, and finally the situation for the Mediterranean and Europe north of the Alps is presented. Human influence on soils has been both beneficial and detrimental. Anthrosols, soils which have been significantly changed by humans, are part of the

ecological inheritance of societies, they can be much more fertile than the unchanged land. Salinization through irrigation and human-induced enhanced erosion are the two most widely known negative influences of humans on soils, making it much less fertile. Under conditions of industrial societies, the nitrogen cycle has expanded to encompass the air. Unsustainable soil use leading to compaction and pollution poses a threat to soils.

All soil histories are local, because soils are so varied. Unlike other fields of environmental history, the environmental history of soils is still in its infancy. Providing long-term data on sustainable and unsustainable use of soils in the past is a daunting task for environmental historians for the next years and decades.

1. Introduction

A comprehensive environmental history of world soils has yet to be written. It would have to combine pedological, historical and archeological perspectives and encompass a multitude of case studies. In such a story, a set of actors new to history would play important roles: soil biota are among the main players. Earthworms do not write history, but they are extremely important in making it, a fact recognized by Charles Darwin, in a book he considered as one of his most important:

"The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earth-worms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures".

Looking at environmental history from a soil perspective reveals several striking cases of unsustainable soil use, but also by a steady stream of human knowledge acquisition and technical ingenuity to deal more sustainably with this prime resource. The biblical proverb that we all come from the soil and shall return to it holds true in the very literal sense of the word: Our deceased bodies are decomposed by specialized soil organisms, releasing nutrients for the growth of vegetation and hence, all life. Only some human cultures hold soils sacred, only some cultures have learned to produce fertile soils from barren ones, but all cultures have developed some sense of the importance of soils.

Soils are central to the biogeochemical cycles of the world, they interact with the hydrosphere as well as with the atmosphere, and are themselves part of the biosphere.

The soil sphere is called the pedosphere, recognizing its unique characteristics. Dirt, although a recent popular book on soils wishes to suggest otherwise, is different from soils: Dirt is under fingernails, soil is the living matrix of life on which we walk.

While concern about soils on the part of scientists has a long history, with contributions such as Bennet's and Chapline's plea to combat erosion of 1928 standing out, a self-aware environmental history of soils is a relatively young phenomenon. But readers will find discussions pertaining to the environmental history of soils in the context of soil science, agricultural history, anthropology and archaeology. In the following paragraphs, a soil science primer offers the necessary basics. The subsequent chapters trace soils as a material entity and soils in the mind through historically and geographically distinct cases. The final paragraphs discuss implications for sustainability.

2. A Soil Science Primer

Soils are varied and manifold. According to the most widely accepted attempts at classifying them, 12 soil orders and a multitude of sub-orders and classes can be discerned. While the air can be viewed as largely homogeneous, and its origin is of little concern for historians, one must understand the formation of soils, because their resulting qualities are so different and because cultivation is a major factor interacting with soil development.

The natural history of soil is called pedogenesis, an evolutionary development of soils over time which was first described fully by the Russian soil scientist Dokuchaev in the late 19th century. The human history of soils is the history of their cultivation. Taken together, natural and human history create the history of human interaction with soils, their environmental history.

Hans Jenny first detailed the factors of soil formation: climate, parent rock material, topography and organisms interact to form soils. Soils form the surface layer of the earth in a range from several meters thickness to a few centimeters.

There is no single definition of soil that all soil scientists accept, but most would agree that soils are three-dimensional entities composed of mineral and organic matter, with their own architecture comprising micro- and macropores through which water and air circulate, and particles of different sizes and surface textures, which form a multitude of quite different habitats for microbial and macroscopic soil organisms. Particle size is an important soil characteristic, with sand, silt and clay being the three categories most often discerned in order of decreasing particle size. A typical soil (if such a thing exists) consists of roughly 25 % each of air and water, 45 % mineral particles, and 5 % soil organic matter (SOM), most of which is comprised of large organic compounds called humus. The rest of SOM is roots and soil organisms. Processes in soils can be physical (such as aggregate formation), chemical (such as nutrient dissolution and leaching) or biological (such as earthworm digestive action). Taken together they control a major part of global biogeochemical cycles, in particular the cycling of reactive nitrogen, and of carbon and its compounds.

Soil processes (in all three senses) depend very much on surfaces, and many involve exchanges at active surfaces such as clay minerals offer. The origin of life itself has been associated with the active surfaces of clay minerals. Besides surfaces, much in soils depends on the organic constituents. The rhizosphere, the soil region in direct contact with plant roots, is a zone not only of increased microbiological activity, but its own chemical characteristics. These influence nutrient uptake and thus, the perceived fertility of the soil. SOM content is decisive for water uptake and storage ability, influences pore structure and microbial activity and hence is crucial for the role of soils as sinks or sources of greenhouse gases. Cultivation lowers SOM content. Agricultural techniques such as manuring or plowing in stubble are geared at restoring SOM in cultivated soils.

2.1. Soils and Their Fertility

Agriculture intervenes into the biodiversity of ecosystems. It transforms them in a planned way by management of the agro-ecosystem, e.g. by crop selection. It also influences associated biodiversity, made up from organisms which colonize the agro-ecosystem after it has been set up by the farmer. The combination of both is responsible for ecosystem functions in an agro-ecosystem. Much of this associated biodiversity is that of the soil, which only came to be recognized with the development of soil microbiology in the second half of the 19th century. One cubic centimeter of soil can contain more than 1 000 000 bacteria. A hectare of pasture land in a humid mid-latitude climate can contain more than a million earthworms and several million insects. Biological and chemical activity is concentrated in the uppermost 10–15 cm of soil, but there is more to soils than the uppermost layer. Pedogenesis does not create uniform mixtures of particles. Most soils are multi-layered, "soil profiles" over depth serve as the main discriminator between soil types. Most existing overviews for a general readership give details about soil types by profile.

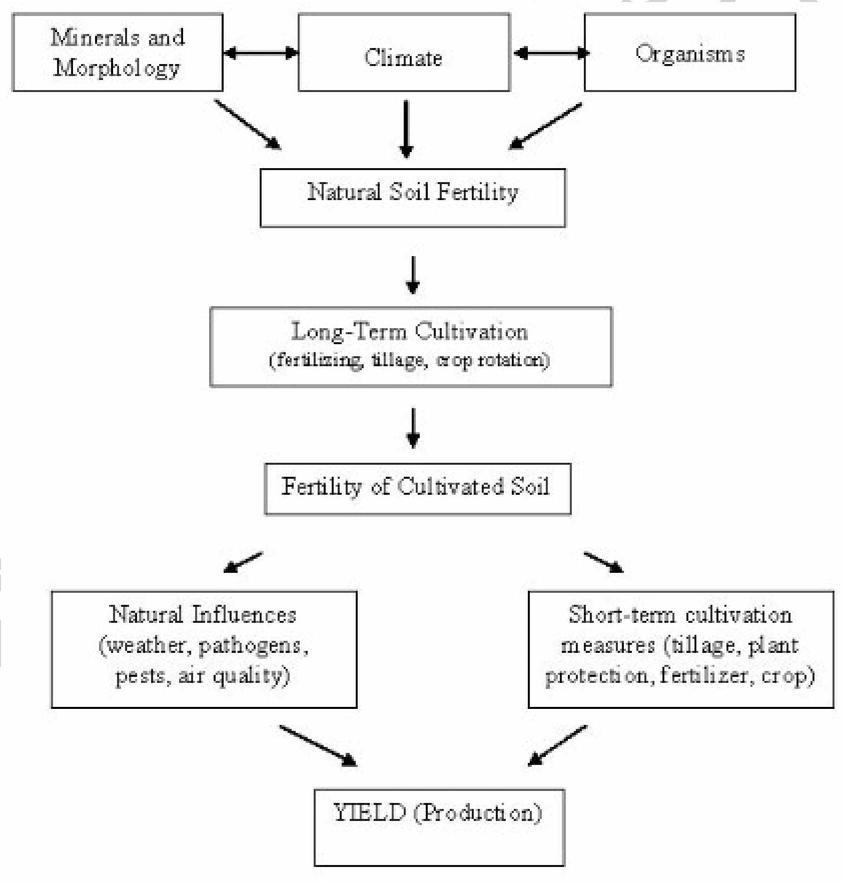

Figure 1. Factors influencing yield in agro-ecosystems. After Gisi, U., Schenker, R., Schulin, R., Staelmann, F.X. and Sticher, H. (^{2}1997). Bodenökologie, 237. Stuttgart, New York: Thieme

Questions of soil fertility are more important for the historian, as it is the productive relation with the soil which is the most decisive in human history. Patzel et al. have shown that the concept of soil fertility itself is not historically stable. Nowadays productive soils are conceptualized as systems governed by both natural and anthropogenic factors. In Figure 1 factors influencing yield in an agro-ecosystem are shown. The natural fertility depends on the factors identified by Jenny, of which all but time are depicted, minerals and morphology being combined into one factor. Long-lasting interventions by humans change a soil profoundly, so that the resulting fertility of the cultivated soil can be much greater than the natural one (e.g. in the case of plaggen soils). While this cultivated fertility can be considered an acquired long- or at least mid-term characteristic of soils, the yearly yield will depend on short term influences of both natural and anthropogenic origin. If human interventions lower fertility, one speaks of anthropogenic soil degradation.

Soil ecosystems are complex in many ways this primer cannot adequately address. As but one example, Figure 2 shows factors influencing the availability of nutrients. Not all nutrient pools in the soil, are available to plants, and the soluble fraction can be quite small, but on the other hand fully mobile ions run the highest risk of being leached, nutrient management thus tries to create large amounts of easily exchangeable nutrients which are bound to surfaces.

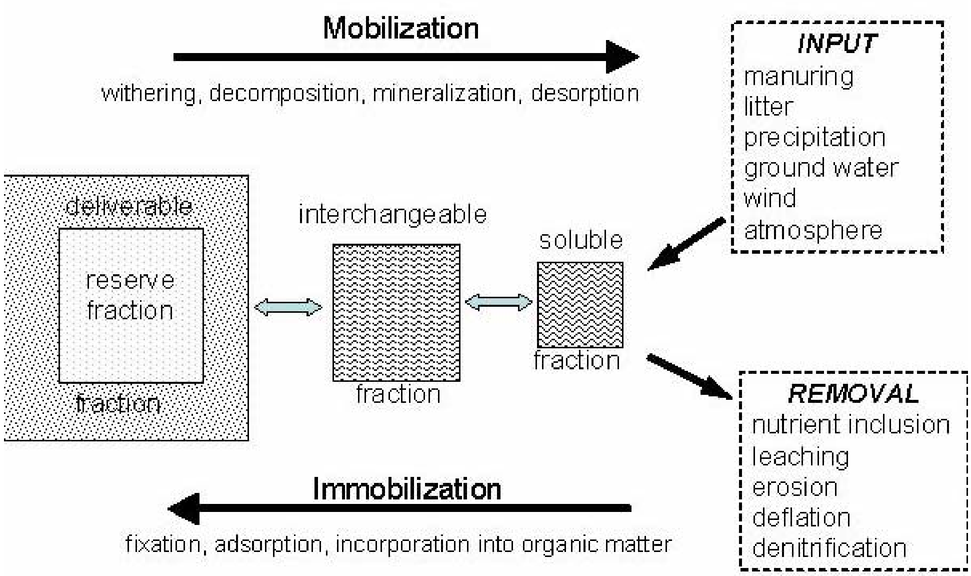

Figure 2. Nutrient behavior in soils under human influence. Adapted from Kuntze, H., Roeschmann, G. and Schwerdtfeger, G. (1994) Bodenkunde, 202. Stuttgart: UTB Ulmer.

Nutrient balances are the sum of several dynamic equilibria, with (1) fertilization and deposition from the atmosphere as external input parameters, (2) mineralization as most important factor particular to the soil and (3) nutrient export by harvesting products and through various kinds of removal such as leaching or wind erosion. The other factor particular to the soil type is the rate of immobilization. Their interplay results in the fertility at a given point and place.

The chemist Justus von Liebig (1803–1873) played an epochal role in the development of soil nutrition. He popularized a "Law of the Minimum", stating that if one crop nutrient is missing or deficient, plant growth will be poor, even if the other elements are abundant. This is not surprising. Just like humans, plants require a balanced diet. Apart from carbon, the basic building block of life, the main elements they require are nitrogen, potassium and phosphorus, sulfur, magnesium and calcium. Plants also require a whole array of micro-nutrients. Modern fertilizers are tuned to different crops by their micro-nutrient content. Just like humans, plants can get too much of a good thing, too: especially sodium ions are stressful for many plants, with the exception of salt-tolerant, halophytic species such as date palms or barley. Salinization, the buildup of high sodium chloride levels, often a consequence of irrigation, therefore threatens yields.

2.2. Soil Functions and Threats to Soils

Soils perform several key functions, apart from their role in biomass production. They are filters and buffers and perform transformations between the atmosphere, the ground water and the plant cover, strongly influencing the water cycle at the earth's surface as well as the gas exchange between terrestrial and atmospheric systems. Soils are also a biological habitat and gene reserve, supporting a large variety of organisms. Soils contain more species in number and quantity than all aboveground ecosystems. Therefore, soils are a main basis of biodiversity. Soils are also the physical basis for technical, industrial and socio-economic structures and their development. Independent of all aforementioned functions, soils are a source of raw materials, e.g. of clay, sand, gravel and minerals in general, as well as a source of geogenic energy and water. Furthermore, soils are a cultural heritage, protecting valuable paleontological and archaeological remnants. The roles soils are expected to play for humans often exclude one another, leading to conflicts about land-use such as those encountered between nature protection and infrastructure development or quarrying.

Next to human-induced erosion and salinization, nutrient depletion is the most prevalent damage to soil ecosystems inflicted by humans. Commonly, all these processes are subsumed as 'soil degradation'. In the UNCCD definition, degradation is defined as "reduction or loss of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water, (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation".

Land-use resulting in the covering of soils with concrete and other materials to use them for infrastructural purposes is a further major threat to soils, particularly close to urban agglomerations. It is important to keep in mind that soils. Like all ecosystems, are dynamic entities. Soils can be changed through management-induced or through natural processes.

2.2.1. Erosion

Apart from impairments of soil quality, the mobility of soil as such is an important issue. A term often used for soil mobility is "erosion". Erosion is a natural process which shapes the earth in an interplay with other processes such as volcanism and tectonics. Through the action of water and wind, mountains are reduced to sand, and within geological times, sediments undergo metamorphism and uplift and end as sandstone mountains, beginning the cycle anew. Erosion can benefit agriculture, as its result, alluvial deposits or aeolian sediments such as loess are prime land for cultivation. About 100–200 tons per square kilometer of new soils are currently formed annually by weathering processes.

Erosion processes can often reach dangerous velocity and extent due to human intervention. Enhanced erosion is a worldwide problem, but particularly pronounced in tropical and subtropical climates. Between 1958 and 2001, a terrace in the central loess plateau of China lost 3400 m^3 km^{-2} a^{-1} of soil. A fluvial catchment on clayey substratum in the Transkei region of the Eastern Cape Province in South Africa displayed erosion of 5400 T km^{-2} a^{-1} between 1949 and 1975. In the loess region of the Palouse, Washington and Idaho, USA, about 7600 T km^{-2} a^{-1} were eroded between 1980 and 1998 and on deeply weathered crystalline rocks in Brazil 17 000 m^3 or 23 000 T km^{-2} a^{-1} were displaced between 1850 and 1979. These measured Brazilian soil destruction rates are more than 100 times higher than the average rate of regeneration of soil material by weathering the regeneration rates. Erosion processes like this are potentially able to remove the entire soil cover in a few centuries and would then prevent agricultural use on the long term. But the upscaling of such results is not easy. Continent-wide estimations seem to be rather doubtful as they are not based on representative data, much remains incompletely understood.

Humans have been aware of soil movement for a long time. In some places (such as the Andes and central Mexico), soil erosion was stimulated by humans so that soil could be collected and concentrated to create agricultural surfaces. In other locations (e.g. Central and West Africa, northern Mexico), soil management systems were designed to minimize or prevent soil erosion associated with tillage and vegetation, or to contain soil movement within a field by using vegetative boundaries. Where large scale crop production developed to supply distant markets, soil erosion was often ignored, proceeded unchecked by human intervention, and led to large scale soil loss.

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Biographical Sketch

Verena Winiwarter is Dean of the Faculty for Interdisciplinary Studies at the Vienna Campus of the Alpen-Adria University Klagenfurt and a professor of Environmental History there. After training in chemistry (HTBLVA 17, Vienna) and several years of working in a research laboratory, she took a degree in history and media studies at the University of Vienna where she became interested in the environmental history of agricultural societies, in particular soils. She has published several studies on the subject of soils in Antiquity and Early Modern Europe and is co-editor (with J.R. McNeill) of “Soils and Societies. Perspectives from Environmental History“ (White Horse Press, 2007). From 2003-2006 she held an APART research fellowship by the Austrian Academy of Sciences, where is currently a member of the Commission on Interdisciplinary Ecological studies. Her Habilitation is in Human Ecology. A founding member of the European Society for Environmental History, she served as their president from 2001-2005 and has been actively involved in the founding of ICEHO, the International Consortium of Environmental History Organizations, which held its first World Congress in 2009. Her CV and list of publications can be found at: http://umweltgeschichte.uni-klu.ac.at/winiwarter.php