SOIL AND ITS LIFE SUPPORT SYSTEMS

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Keywords: soil, natural resources, civilization, soil functions, soil processes, global challenges, food security, degradation, world population, soil science, soil physics, soil chemistry ,fertility, soil microbiology, water quality

Contents

1. Introduction

Soil is the most basic of all natural resources. It is the three-dimensional layer of earth's crust, which, through numerous biophysical/chemical interactive processes, is capable of supporting plant and animal life and moderating air and water (environment) quality. Soil is a living entity, it is teeming with life, it is a substrate for plant growth, and ceases to support plant growth and purify water and air when life in it ceases to exist. Soil and life have evolved together and will continue to develop together. Because of its strong co-dependence on life, soils may be defined as "dynamic natural bodies comprising the uppermost layer of the earth, exhibiting distinct organization of their mineral and organic components, including water and air, which formed in response to atmospheric and biospheric forces acting on various parent materials under diverse topographic conditions over a period of time" (1). Soil, or the pedosphere, lies at the interface of the atmosphere and the lithosphere and interacts with all facets of the environment (Figure 1). Indeed, soil is in dynamic equilibrium with its environment, it influences and is influenced by the environment. Soil's interaction with the lithosphere leads to weathering of rocks and new soil formation through leaching of organic and inorganic chemicals into the rock, penetration of plant roots and encroachment of other organisms. Soil's interaction with atmosphere involves exchange of gases, notably CO_2 and N_2, with a profound impact on global climate and plant growth. Soil's interaction with hydrosphere affects water quality because of its ability to filter, denature and buffer against natural and synthetic compounds. It is soil's interaction with the biosphere that has led to co-evolution of life and soil. Soil is the most basic of all natural resources to human survival on the earth. Soil governs all basic processes that regulate the existence of life on earth. These processes are: (i) plant growth and biomass productivity, (ii) purification of water, (iii) detoxification of pollutants, (iv) recycling of elements, and (v) resilience and restoration of ecosystems. This chapter deals with the basic processes governing interaction between pedosphere and the biosphere, and describes future challenges for soil science to meet the demand of the 21st century and aspirations of the growing population.

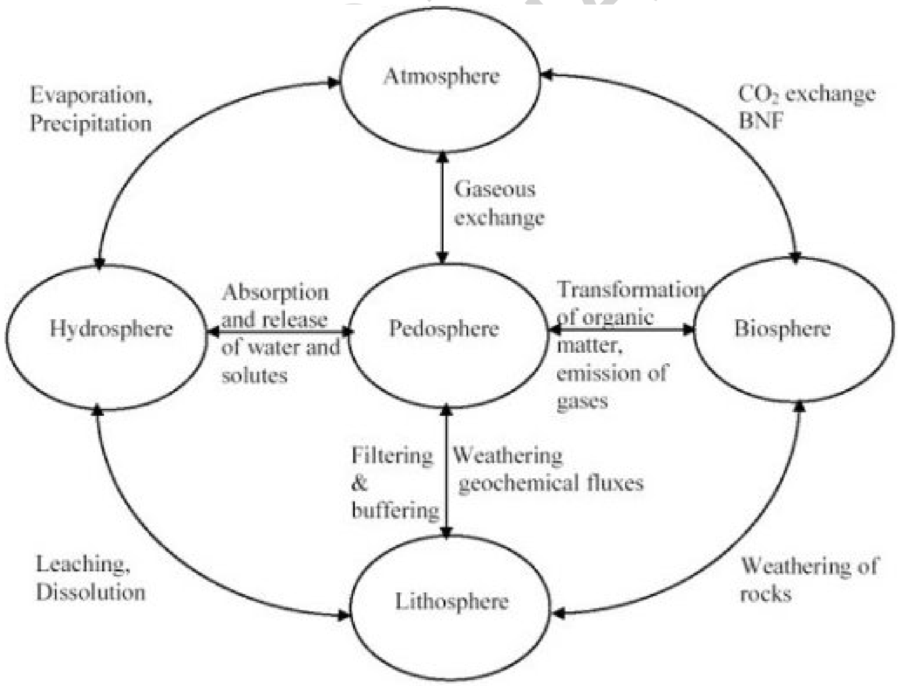

Figure 1. Interaction between Soil and the Environment

2. Soil Attributes

Soils are characterized by physical, chemical and biological attributes collectively termed as soil quality (Figure 2). Soil quality refers to its ability to perform functions of value to humans (2), but specifically to its capacity to produce biomass and moderate the environment (3; 4). These attributes differ among soils because of their development/formation from specific parent material, climate, predominant vegetation, soil moisture regime, drainage intensity and position on the landscape (5). Soil physical properties include particle size distribution, especially the amount of clay content and nature of clay minerals, degree and stability of aggregates, and total porosity and pore size distribution. These properties determine the relative proportion of solid:liquid:gasesous phases, and water retention and transmission properties. Important processes governed by soil properties are gaseous exchange between soil and the atmosphere, root growth and development, soil erosion among others. Strongly interacting with physical properties are soil chemical characteristics including pH, ion exchange capacity, elemental (N, P, S, K, Ca, Mg etc.) concentration and their solubility, and elemental balance as expressed by relative concentrations of predominant elements. Important processes relevant to soil chemical characteristics include leaching, acidification, ionic diffusion, chemical transformations and redox phenomena. Soil biological attributes, with strong impact on physical and chemical qualities, include quantity and quality of soil organic matter, total and microbial biomass carbon, and activity and species diversity of soil fauna. Soil processes associated with biological attributes are mineralization, fluxes of trace gases from soil to the atmosphere, purification of water and detoxification of chemicals and other pollutants. Sustainable management of soil physical, chemical and biological qualities is the goal of adopting a judicious land use and appropriate management systems.

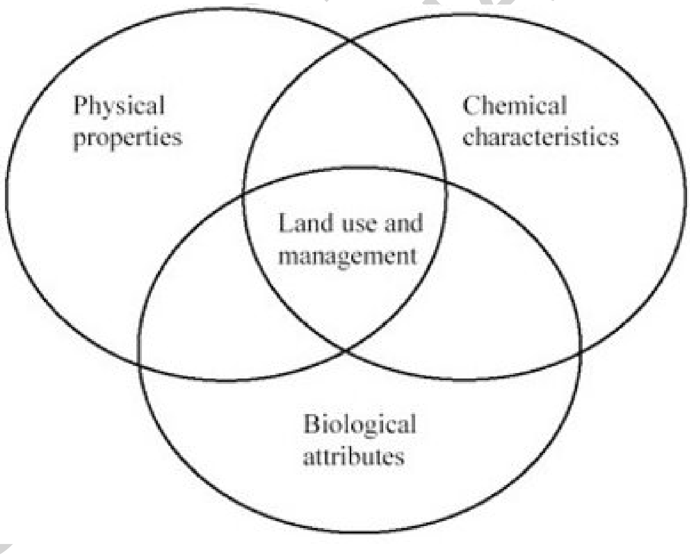

Figure 2. Soil quality depends on dynamic equilibrium between physical, chemical and biological properties and processes, and on land use and management

3. Soil and Civilization

Realizing that life depended on soil and its ability to support plant growth, ancient societies worshipped soil in one form or another (6). Prior to the developments of modern science, inter-dependence of ancient human societies and soil occurred in three forms (Figure 3).

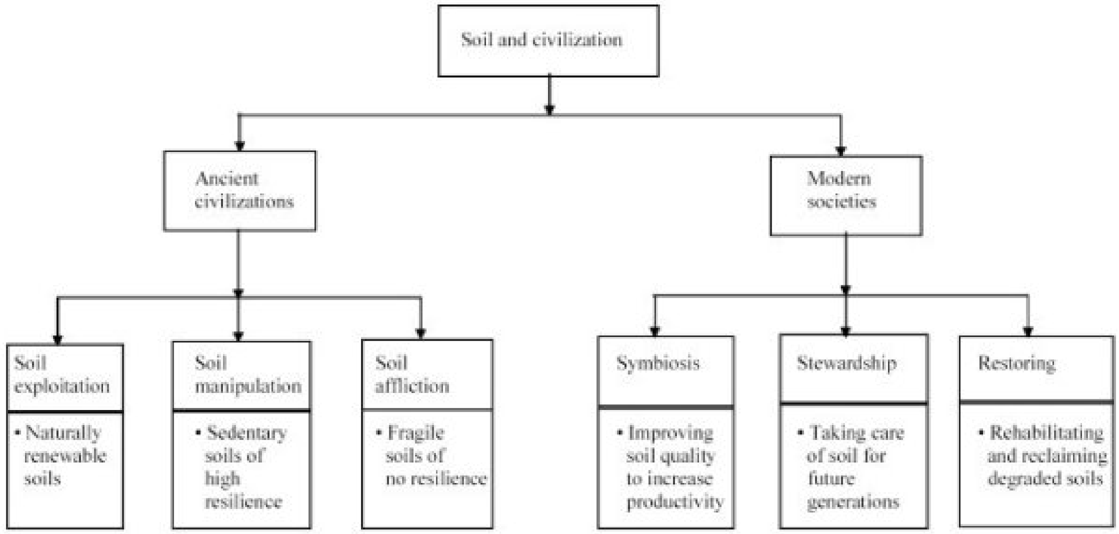

Figure 3. Soil-human interactions between ancient and modern civilizations

3.1. Soil exploitation

Humans have exploited soil resources for raising crops and animals, similar to a parasite's exploitation of its host organism, ever since the dawn of settled agriculture around 10-13 millennia ago (7). Naturally exploitable soils, supporting human settlement over a long period of time, comprised those that were frequently renewed by natural processes. A prime example is alluvial soils annually renewed by floods. The so-called "hydric civilizations" (e.g., ancient cultures developed along the valleys of major river systems such as the Nile, Indus, Euphrates-Tigris, Yangtze etc.), exploited the natural renewability of alluvial soils (6). With expansion of human settlement to other ecoregions, soil exploitation has been the basis of numerous traditional systems of farming such as shifting cultivation and bush fallow rotation (8). Rather than annual floods, fertility of these upland soils was renewed by fallowing or abandoning the land for a long period of time.

3.2. Soil manipulation

Non-renewable soils cannot sustain plant/crop growth over a long period of time without alterations/manipulation of its life support processes. Principal systems of soil manipulation developed by ancient civilizations were plowing, terracing, irrigation and manuring. Between 5000 and 4000 BC, Sumerian and other civilizations developed simple tools to place and cover seeds in the soil, which eventually evolved into a plow. Cultivation of sloping lands, where accelerated soil erosion threatened sustainable use, led to evolution of the "terraced" system of farming. Terraced agriculture is a cultural tradition in many ancient civilizations in the Middle East (The Phoenicians), West Asia (Yemen), Central and South America (Incas) and South East Asia. Accelerated soil erosion has been a cause of the demise of many ancient cultures (9). Crop production during dry season or in arid regions requires addition of water. Consequently irrigated agriculture evolved around 9500 to 8800 BC in the Middle East, and spread to other cultures (e.g., Sumerians, Babylonians, Asyrians, Egyptians, Harrappan and Chinese) around 4000 to 5000 BC (6). Similar to water, importance of maintaining soil fertility was recognized by Mesopotamian and others since 2500 BC. The practice of manuring dates back to 900 to 700 BC and that of green manuring to 234 to 149 BC (10).

3.3. Soil affliction

Some ancient cultures "afflicted" fragile soils in a manner similar to a pathogen afflicting another organism (7). In the case of fragile soils in harsh environments, such an interaction can lead to collapse of the human society and irreversible loss of the soil. The extinction of many ancient societies (e.g., the Mayan Kingdom in Guatemala) and widespread occurrence of degraded and depleted soils is attributed to this self-destructive interaction between humans and soils.

Modern civilizations, characterized by large populations and numerous demands and aspirations, cannot sustain themselves without a major behavioral change toward soil resources. Humans have to live with soil in a symbiotic relationship based on mutual enhancement, nurturing soil resources to improve their life-support systems, and restoring and rehabilitating degraded soils and ecosystems. The behavioral change (e.g., symbiotic, nurturing and restoring attitude) is necessary to realize all the functions of soil that are necessary to meet the demands and fulfill the aspirations of the rising global population.

4. Soil Functions of Importance to Modern Civilization

Historically, soil has supported plant growth to provide for the basic necessities of life of human societies, namely in the form of food, feed, fiber and fuel. Recent advances in agronomic sciences have dramatically increased soils capacity to produce the needed biomass to meet the needs of increasing human population. These advances include nutrient management technologies to achieve the desired biomass production, water management to optimize the soil moisture regime and create a favorable balance between liquid and gaseous phases, and soil physical manipulation through appropriate tillage methods to create a favorable balance among solid:liquid:gasesous phases and optimize porosity and pore size distribution. Soil is a major repository of germplasm and contains a vast gene pool of flora and fauna. In addition to food production and as a substrate (medium) for plant growth, soil has numerous other functions of importance to modern civilization (1).

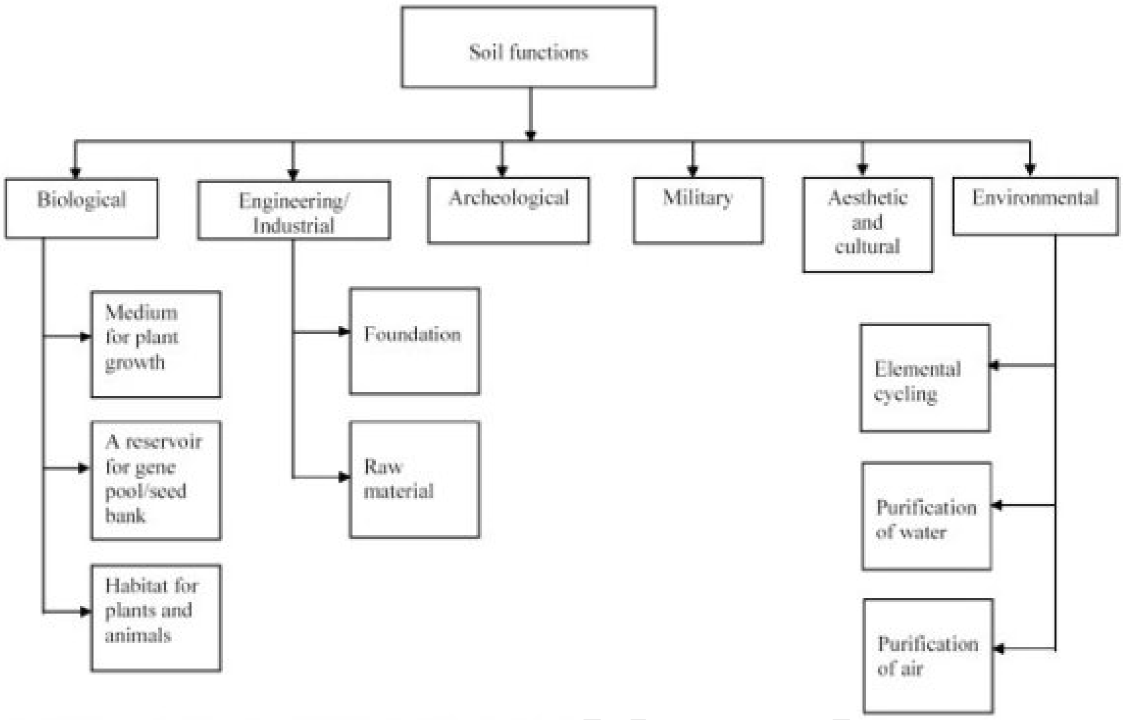

Figure 4. Soil functions of importance to humans and modern civilizations

Soil serves as a geomembrane to denature, filter and buffer against natural and anthropogenic pollutants, thereby moderating quality of natural waters. Depending on land use and management, soil also serves as a repository of C, N and other elements, influences the fluxes of these and other compounds between soil and the atmosphere, and moderates the gaseous composition of trace gases and particulate materials in the atmosphere. Soil is a habitat for flora and fauna (macro, meso and micro), and biotic transformations of organic matter returned to the soil are essential to its ability to perform functions. Soils also have numerous industrial/engineering uses including as a foundation for engineering structure, construction material and as raw material for industrial products (e.g., ceramic, brick-making and as a source of minerals). There are also cultural, archaeological and aesthetic functions of soil. The demand on soil resources continue to increase with increase in human population, and rising aspirations of human society (see Figure 4). In addition to producer of food, soils function as an environment moderator because industrial/engineering raw materials are likely to increase.

5. Soil Processes of Importance to Humans

Soil is a vast reactor and a medium for numerous biochemical and physical transformations. There are numerous processes or reactions that influence the quality of soil and govern its capacity to perform the necessary functions (Figure 5). Important physical processes include erosion, illuviation/eluviation, gaseous exchange via diffusion and mass flow, and infiltration and percolation of water and solutes into and through the soil body. Soil physical processes influence evolution of landscape and fluxes of water, solutes and gases through the soil-plant-atmosphere continuum. Interacting with physical processes are chemical reactions that alter soil reaction, solubility and uptake of elements by plant roots, and movement/accumulation of chemicals in soil solum. Notable chemical processes are solubization, oxidation/reduction, salinization and alkalization. Chemical reactions and transformations govern the availability and uptake of nutrients by plant roots. Biological processes are important to transformation of organic matter into simple inorganic compounds and complex humic substances.

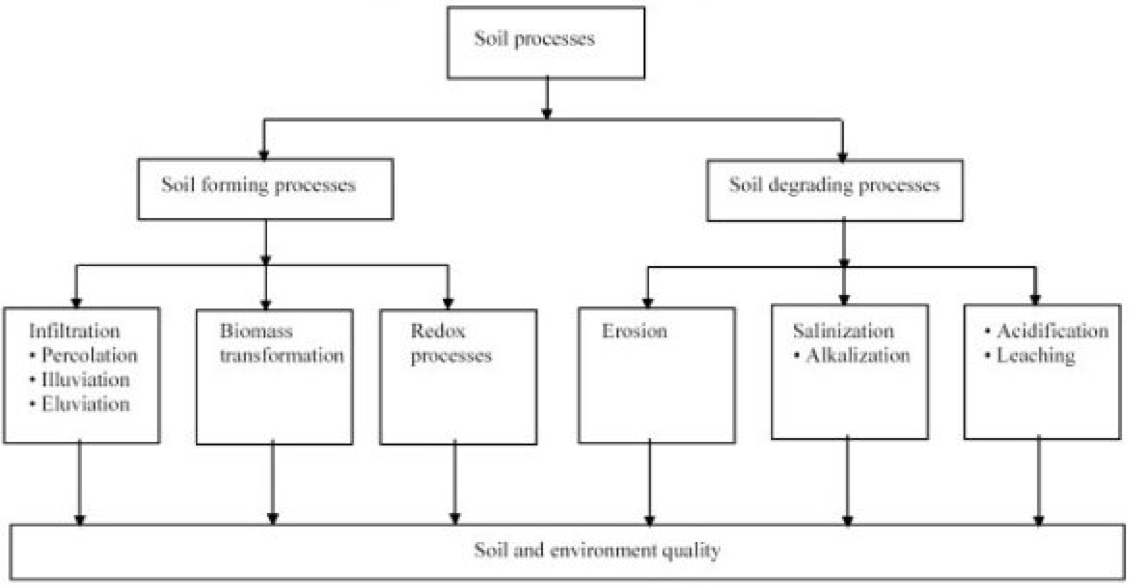

Figure 5. Soill physical, chemical and biological processes that govern soil quality and moderate soil functions

The study of these processes and transformations constitute specific branches of soil science including soil physics, soil chemistry and fertility, and soil microbiology and biochemistry. The branch of soil science dealing with soil forming processes, genesis and classification is called pedology. These specialized studies of soil science involve close interaction with other scientific disciplines to understand complex interactions between soil and the environments (Figure 6). The present and future needs of society can only be met through an inter-disciplinary and holistic approach to understanding properties and processes in soil that affect biomass production and environment quality.

Figure 6. A complete study of soil involves close interaction with basic sciences and engineering

In addition to properties and processes that govern soil quality, there are other soil attributes that must be understood to develop strategies for sustainable management. Important among these are the following:

5.1. Finite extent

World soil resources are finite, especially soils of good quality with few or no limitations for an intensive and continuous use. Total land area of the earth is 13 billion hectares, (Bha) of which the cultivable land is merely 11% or 1.44 Bha. Land suitable for use as permanent meadows and pastures constitute 26% (3.36 Bha), and that for forest and woodlands about 30% (3.89 Bha) (11). Large areas of land are unsuitable for cultivation due to climates that are too cold (permanently frozen) or too hot (desert), barren lands (eroded, salinized) or terrain that is too steep and unfit to cultivate.

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