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Soil Quality and Soil Health: A Review

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ABSTRACT: Soil quality refers to the condition of soil based on its capacity to perform ecosystem services that meet the needs of human and non-human life.[1][2][3][4] Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. In more colloquial terms, the health of soil arises from favorable interactions of all soil components (living and non-living) that belong together, as in microbiota, plants and animals. It is possible that a soil can be healthy in terms of ecosystem functioning but not necessarily serve crop production or human nutrition directly, hence the scientific debate on terms and measurements.

KEYWORDS-soil, quality, health, ecosystem, crop, components

I.INTRODUCTION

Soil quality reflects how well a soil performs the functions of maintaining biodiversity and productivity, partitioning water and solute flow, filtering and buffering, nutrient cycling, and providing support for plants and other structures. Soil management has a major impact on soil quality.

Soil quality relates to soil functions. Unlike water or air, for which established standards have been set, soil quality is difficult to define or quantify.

Indicators of soil quality

Soil quality can be evaluated using the Soil Management Assessment Framework.[5] Soil quality in agricultural terms is measured on a scale of soil value (Bodenwertzahl) in Germany.[6]

Soil quality is primarily measured by chemical, physical, and biological indicators because soil function cannot easily be measured directly.[7] Each of these categories comprises several indicators that provide insight into overall soil quality.[1,2,3]

Physical

The physical category of soil quality indicators consists of tests that measure soil texture, bulk density, porosity, water content at saturation, aggregate stability, penetration resistance, and more.[8] These measures provide hydrological information, such the level of water infiltration and water availability to plants.

Chemical

Chemical indicators include pH and nutrient levels.[9] A typical soil test only evaluates chemical soil properties.[7]

Biological

Biological measures include diversity of soil organisms and fungi.

The movement and biological functions of soil organisms (including earthworms, millipedes, centipedes, ants, and spiders) impact soil processes such as the regulation of soil structure, degradation of contaminants, and nutrient cycling.[10]

II.DISCUSSION

Soil health testing is pursued as an assessment of this status[1] but tends to be confined largely to agronomic objectives. Soil health depends on soil biodiversity (with a robust soil biota), and it can be improved via soil management, especially by care to keep protective living covers on the soil and by natural (carbon-containing) soil amendments. Inorganic fertilizers do not necessarily damage soil health if 1) used at appropriate and not excessive rates and 2) if they bring about a general improvement of overall plant growth which contributes more carbon-containing residues to the soil.

Aspects

The term soil health is used to describe the state of a soil in:

- Sustaining plant and animal productivity (agronomic focus);
- Enhancing biodiversity (Soil biodiversity) (ecological focus);
- Maintaining or enhancing water and air quality (environmental/climate focus);
- Supporting human health and habitation.[2]
- sequestering carbon[3]

Soil Health has partly if not largely replaced the expression "Soil Quality" that was extant in the 1990s. The primary difference between the two expressions is that soil quality was focused on individual traits within a functional group, as in "quality of soil for maize production" or "quality of soil for roadbed preparation" and so on. The addition of the word "health" shifted the perception to be integrative, holistic and systematic. The two expressions still overlap considerably. Soil Health as an expression derives from organic or "biological farming" movements in Europe, however, well before soil quality was first applied as a discipline around 1990. In 1978, Swiss soil biologist Dr Otto Buess wrote an essay "The Health of Soil and Plants" which largely defines the field even today.

The underlying principle in the use of the term "soil health" is that soil is not just an inert, lifeless growing medium, which modern intensive farming tends to represent, rather it is a living, dynamic and ever-so-subtly changing whole environment. It turns out that soils highly fertile from the point of view of crop productivity are also lively from a biological point of view. It is now commonly recognized that soil microbial biomass is large: in temperate grassland soil the bacterial and fungal biomass have been documented to be 1–2 t (2.0 long tons; 2.2 short tons)/hectare and 2–5 t (4.9 long tons; 5.5 short tons)/ha, respectively. [4] Some microbiologists now believe that 80% of soil nutrient functions are essentially controlled by microbes.[5][6]

Using the human health analogy, a healthy soil can be categorized as one:

- In a state of composite well-being in terms of biological, chemical and physical properties;
- Not diseased or infirmed (i.e. not degraded, nor degrading), nor causing negative off-site impacts;
- With each of its qualities cooperatively functioning such that the soil reaches its full potential and resists degradation;
- Providing a full range of functions (especially nutrient, carbon and water cycling) and in such a way that it maintains this capacity into the future.[4,5,6]

Conceptualisation

Soil health is the condition of the soil in a defined space and at a defined scale relative to a set of benchmarks that encompass healthy functioning. It would not be appropriate to refer to soil health for soil-roadbed preparation, as in the analogy of soil quality in a functional class. The definition of soil health may vary between users of the term as alternative users may place differing priorities upon the multiple functions of a soil. Therefore, the term soil health can only be understood within the context of the user of the term, and their aspirations of a soil, as well as by the boundary definition of the soil at issue. Finally, intrinsic to the discussion on soil health are many potentially conflicting interpretations, especially ecological landscape assessment vs agronomic objectives, each claiming to have soil health criteria.

Interpretation

Different soils will have different benchmarks of health depending on the "inherited" qualities, and on the geographic circumstance of the soil. The generic aspects defining a healthy soil can be considered as follows:

- "Productive" options are broad;

- Life diversity is broad;
- Absorbency, storing, recycling and processing is high in relation to limits set by climate;
- Water runoff quality is of high standard;
- Low entropy; and
- No damage to or loss of the fundamental components.

This translates to:

- A comprehensive cover of vegetation;
- Carbon levels relatively close to the limits set by soil type and climate;
- Little leakage of nutrients from the ecosystem;
- Biological and agricultural productivity relatively close to the limits set by the soil environment and climate;
- Only geological rates of erosion;
- No accumulation of contaminants; and,

An unhealthy soil thus is the simple converse of the above.

Measurement

On the basis of the above, soil health will be measured in terms of individual ecosystem services provided relative to the benchmark. Specific benchmarks used to evaluate soil health include CO_2 release, humus levels, microbial activity, and available calcium.[7]

Soil health testing is spreading in the United States, Australia and South Africa.[8] Cornell University, a land-grant college in NY State, has had a Soil Health Test since 2006. Woods End Laboratories, a private soil lab founded in Maine in 1975, has offered a soil quality package since 1985. Both these services combine physical (aggregate stability), chemical (mineral balance), and biological (CO_2 respiration) analyses, which today are considered hallmarks of soil health testing.[9] The approach of other soil labs also entering the soil health field is to add into common chemical nutrient testing a biological set of factors not normally included in routine soil testing. The best example is adding biological soil respiration ("CO_2-Burst") as a test procedure; this has already been adapted to modern commercial labs in the period since 2006.[7,8,9]

There is however resistance among soil testing labs and university scientists to add new biological tests, primarily because the established metric of soil fertility is largely based on models constructed from "crop response" studies, which match crop yield to specific chemical nutrient concentrations, and no similar models appear to exist for soil health tests. Critics of novel soil health tests argue that they may be insensitive to management changes.[10]

Soil test methods have evolved slowly over the past 40 years. However, in this same time USA soils have also lost up to 75% of their carbon (humus), causing biological fertility and ecosystem functioning to decline; how much is debatable. Many critics of the conventional system say the loss of soil quality is sufficient evidence that the old soil testing models have failed us, and need to be replaced with new approaches. These older models have stressed "maximum yield" and " yield calibration" to such an extent that related factors have been overlooked. Thus, surface and groundwater pollution with excess nutrients (nitrates and phosphates) has grown enormously, and early 2000s measures were reported (in the United States) to be the worst it has been since the 1970s, before the advent of environmental consciousness.[11][12][13]

Soil health gap

Importance of soil for global food security, agro-ecosystem, environment, and human life has exponentially shifted the trends of research towards soil health. However, lack of a site/region specific benchmark has limited the research effort towards understanding the true effect of different agronomic managements on soil health. In 2020, Maharjan and his team, introduces a new term and concept "Soil Health Gap" and described how native land in particular region can help in establishing the benchmark to compare the efficacies of different management practices and at the same time it can be used in understanding quantitative difference in soil health status.[14]

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III.RESULTS

Soil management is the application of operations, practices, and treatments to protect soil and enhance its performance (such as soil fertility or soil mechanics). It includes soil conservation, soil amendment, and optimal soil health. In agriculture, some amount of soil management is needed both in nonorganic and organic types to prevent agricultural land from becoming poorly productive over decades. Organic farming in particular emphasizes optimal soil management, because it uses soil health as the exclusive or nearly exclusive source of its fertilization and pest control.

Soil management is an important tool for addressing climate change by increasing soil carbon and as well as addressing other major environmental issues associated with modern industrial agriculture practices. Project Drawdown highlights three major soil management practices as actionable steps for climate change mitigation: improved nutrient management,[1] conservation agriculture (including No-till agriculture),[2] and use of regenerative agriculture.[3]

Environmental impact

According to the EPA, agricultural soil management practices can lead to production and emission of nitrous oxide (N_2O), a major greenhouse gas and air pollutant. Activities that can contribute to N_2O emissions include fertilizer usage, irrigation and tillage. The management of soils accounts for over half of the emissions from the Agriculture sector. Cattle livestock account for one third of emissions, through methane emissions. Manure management and rice cultivation also produce emissions.[4] Using biochar may decrease N_2O emissions from soils by an average of 54%.[5] the usage of artificial fertilizer in the agricultural field it leads to nutrition imbalance in the soil.[10,11,12]

Soils can sequester carbon dioxide (CO_2) from the atmosphere, primarily by storing carbon as soil organic carbon (SOC) through the process of photosynthesis. CO_2 can also be stored as inorganic carbon but this is less common. Converting natural land to agricultural land releases carbon back into the atmosphere. The amount of carbon a soil can sequester depends on the climate and current and historical land-use and management.[6] Cropland has the potential to sequester 0.5–1.2 Pg C/year and grazing and pasture land could sequester 0.3–0.7 Pg C/year.[7] Agricultural practices that sequester carbon can help mitigate climate change.[8] Intensive farming deteriorates the functionality of soils.

Methods that significantly enhance carbon sequestration in soil include no-till farming, residue mulching, cover cropping, and crop rotation, all of which are more widely used in organic farming than in conventional farming.[9][10] Because only 5% of US farmland currently uses no-till and residue mulching, there is a large potential for carbon sequestration.[11] Similar practices such as arable land conversion to grasslands, crop residues and cover crops have been proposed in Europe.[12]

Practices

Conventional agriculture is driven by industrialization and aims to maximize efficiency. Practices include large-scale farming that specializes in monoculture and uses pesticides, herbicides, and fertilizers.[8][13] Alternatives include conservation, regenerative, and organic agriculture, which can be broadly grouped as sustainable agriculture. Conservation agriculture has three main practices: minimizing soil disturbance, maintaining permanent soil coverage, and diversifying crop species.[14] Similarly, regenerative agriculture practices use minimal to no tillage, cover crops, crop rotations, compost, and grazing.[15] Organic agriculture incorporates most of these practices and emphasizes biological, not synthetic, management.[16] There are three overarching practices that improve carbon sequestration in soils: increasing biomass inputs, decreasing SOC losses, and increasing the mean residence time (MRT) of SOC.[7]

Specific soil management practices that affect soil health include:[17]

- Controlling traffic on the soil surface helps to reduce soil compaction, which can reduce aeration and water infiltration.
- Planting cover crops that keep the soil anchored and covered in off-seasons so that the soil is not eroded by wind and rain.

- Crop rotations[18] for row crops alternate high-residue crops with lower-residue crops to increase the amount of plant material left on the surface of the soil during the year to protect the soil from erosion.
- Nutrient management can help to improve the fertility of the soil and the amount of organic matter content, which improves soil structure and function.
- Tilling the soil, or tillage, is the breaking of soil, such as with a plough or harrow, to prepare the soil for new seeds. Tillage systems vary in intensity and disturbance. Conventional tillage is the most intense tillage system and disturbs the deepest level of soils. At least 30% of plant residue remains on the soil surface in conservation tillage.[19][20] Reduced-tillage or no-till operations limit the amount of soil disturbance while cultivating a new crop, and help to maintain plant residues on the surface of the soil for erosion protection and water retention.
- Adding organic matter to the soil surface can increase carbon in the soil and the abundance and diversity of microbial organisms in the soil.[21][22]
- Using fertilizers increases nutrients such as nitrogen, phosphorus, sulfur, and potassium in the soil. The use of fertilizers influences soil pH and often acidifies soils, with the exception of potassium fertilizer.[23] Fertilizers can be organic or synthetic.
- Using a perennial grain crop such as Thinopyrum intermedium.

IV.CONCLUSION

Soil conservation is the prevention of loss of the topmost layer of the soil from erosion or prevention of reduced fertility caused by over usage, acidification, salinization or other chemical soil contamination.

Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some lesser developed areas. A consequence of deforestation is typically large-scale erosion, loss of soil nutrients and sometimes total desertification. Techniques for improved soil conservation include crop rotation, cover crops, conservation tillage and planted windbreaks, affect both erosion and fertility. When plants die, they decay and become part of the soil. Code 330 defines standard methods recommended by the U.S. Natural Resources Conservation Service. Farmers have practiced soil conservation for millennia. In Europe, policies such as the Common Agricultural Policy are targeting the application of best management practices such as reduced tillage, winter cover crops,[1] plant residues and grass margins in order to better address soil conservation. Political and economic action is further required to solve the erosion problem. A simple governance hurdle concerns how we value the land and this can be changed by cultural adaptation.[2] Soil carbon is a carbon sink, playing a role in climate change mitigation.[3]

Contour ploughing

Contour ploughing orients furrows following the contour lines of the farmed area. Furrows move left and right to maintain a constant altitude, which reduces runoff. Contour plowing was practiced by the ancient Phoenicians for slopes between two and ten percent.[4] Contour plowing can increase crop yields from 10 to 50 percent, partially as a result of greater soil retention.[5]

Terrace farming

Terracing is the practice of creating nearly level areas in a hillside area. The terraces form a series of steps each at a higher level than the previous. Terraces are protected from erosion by other soil barriers. Terraced farming is more common on small farms. This involves creating a series of flats terraced levels on a sloping field.

Keyline design

Keyline design is the enhancement of contour farming, where the total watershed properties are taken into account in forming the contour lines.

Perimeter runoff control

Tree, shrubs and ground-cover are effective perimeter treatment for soil erosion prevention, by impeding surface flows. A special form of this perimeter or inter-row treatment is the use of a "grass way" that both channels and dissipates runoff through surface friction, impeding surface runoff and encouraging infiltration of the slowed surface water.[6]

Windbreaks

Windbreaks are sufficiently dense rows of trees at the windward exposure of an agricultural field subject to wind erosion.[7] Evergreen species provide year-round protection; however, as long as foliage is present in the seasons of bare soil surfaces, the effect of deciduous trees may be adequate.[13]

Cover crops/crop rotation

Cover crops such as nitrogen-fixing legumes, white turnips, radishes and other species are rotated with cash crops to blanket the soil year-round and act as green manure that replenishes nitrogen and other critical nutrients. Cover crops also help to suppress weeds.[8]

Soil-conservation farming

Soil-conservation farming involves no-till farming, "green manures" and other soil-enhancing practices which make it hard for the soils to be equalized. Such farming methods attempt to mimic the biology of barren lands. They can revive damaged soil, minimize erosion, encourage plant growth, eliminate the use of nitrogen fertilizer or fungicide, produce above-average yields and protect crops during droughts or flooding. The result is less labor and lower costs that increase farmers' profits. No-till farming and cover crops act as sinks for nitrogen and other nutrients. This increases the amount of soil organic matter.[8]

Repeated plowing/tilling degrades soil, killing its beneficial fungi and earthworms. Once damaged, soil may take multiple seasons to fully recover, even in optimal circumstances.[8]

Critics argue that no-till and related methods are impractical and too expensive for many growers, partly because it requires new equipment. They cite advantages for conventional tilling depending on the geography, crops and soil conditions. Some farmers have contended that no-till complicates pest control, delays planting and that post-harvest residues, especially for corn, are hard to manage.[8]

Reducing the use of pesticides

The use of pesticides can contaminate the soil, and nearby vegetation and water sources for a long time. They affect soil structure and (biotic and abiotic) composition.[9][10] Differentiated taxation schemes are among the options investigated in the academic literature to reducing their use.[11]

Alternatives to pesticides are available and include methods of cultivation, use of biological pest controls (such as pheromones and microbial pesticides), genetic engineering (mostly of crops), and methods of interfering with insect breeding.[12] Application of composted yard waste has also been used as a way of controlling pests.[13]

These methods are becoming increasingly popular and often are safer than traditional chemical pesticides. In addition, EPA is registering reduced-risk pesticides in increasing numbers.

Salinity management

Salinity in soil is caused by irrigating with salty water. Water then evaporates from the soil leaving the salt behind. Salt breaks down the soil structure, causing infertility and reduced growth.

The ions responsible for salination are: sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chlorine (Cl^-). Salinity is estimated to affect about one third of the earth's arable land.[14] Soil salinity adversely affects crop metabolism and erosion usually follows.

Salinity occurs on drylands from overirrigation and in areas with shallow saline water tables. Over-irrigation deposits salts in upper soil layers as a byproduct of soil infiltration; irrigation merely increases the rate of salt deposition. The best-known case of shallow saline water table capillary action occurred in Egypt after the 1970 construction of the Aswan Dam. The change in the groundwater level led to high salt concentrations in the water table. The continuous high level of the water table led to soil salination.

Use of humic acids may prevent excess salination, especially given excessive irrigation. Humic acids can fix both anions and cations and eliminate them from root zones.

Planting species that can tolerate saline conditions can be used to lower water tables and thus reduce the rate of capillary and evaporative enrichment of surface salts. Salt-tolerant plants include saltbush, a plant found in much of North America and in the Mediterranean regions of Europe.

Soil organisms

When worms excrete feces in the form of casts, a balanced selection of minerals and plant nutrients is made into a form accessible for root uptake. Earthworm casts are five times richer in available nitrogen, seven times richer in available phosphates and eleven times richer in available potash than the surrounding upper 150 millimetres (5.9 in) of soil. The weight of casts produced may be greater than 4.5 kg per worm per year. By burrowing, the earthworm improves soil porosity, creating channels that enhance the processes of aeration and drainage.[15]

Other important soil organisms include nematodes, mycorrhiza and bacteria. A quarter of all the animal species live underground. According to the 2020 Food and Agriculture Organization's report "State of knowledge of soil biodiversity – Status, challenges and potentialities", there are major gaps in knowledge about biodiversity in soils.[16][17]

Degraded soil requires synthetic fertilizer to produce high yields. Lacking structure increases erosion and carries nitrogen and other pollutants into rivers and streams.[8]

Each one percent increase in soil organic matter helps soil hold 20,000 gallons more water per acre.[8]

Mineralization

To allow plants full realization of their phytonutrient potential, active mineralization of the soil is sometimes undertaken. This can involve adding crushed rock or chemical soil supplements. In either case the purpose is to combat mineral depletion. A broad range of minerals can be used, including common substances such as phosphorus and more exotic substances such as zinc and selenium. Extensive research examines the phase transitions of minerals in soil with aqueous contact.[18]

Flooding can bring significant sediments to an alluvial plain. While this effect may not be desirable if floods endanger life or if the sediment originates from productive land, this process of addition to a floodplain is a natural process that can rejuvenate soil chemistry through mineralization.[14]

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