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A Review on the Interactive Exploration of Soil Health and How to Improve It to Boost Crop Production

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ABSTRACT

Soil health is becoming so important these days as a result of more and more, producers are understanding that healthy soils are more productive and lead to healthier crops. This led to more about sustainable production practices that can help build healthy soil that can sustain the production of healthier crops to the populace. These can be achieved by exploring the on-farm benefits of using cover crops, crop rotation, manure amendments, composting and more on the complex web of life below the surface of the soil in order to improve them. Soil management encompasses a number of strategies used by farmers and ranchers to protect soil resources, one of their most valuable assets. By practicing soil conservation, including appropriate soil preparation methods, they reduce soil erosion and increase soil stabilization. Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. Soil health testing is an assessment of this status. Soil health depends on soil biodiversity (with a robust soil biota), and it can be improved via soil conditioning. The underlying principle in the use of the term "soil health" is that soil is not just an inert, lifeless growing medium, which modern farming tends to represent, rather it is a living, dynamic and ever-so-subtly changing whole environment. 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 a point in time. Different soils will have different benchmarks of health depending on the "inherited" qualities, and on the geographic circumstance of the soil The pressure that we impose on the soil in terms of biosphere (direct human impacts included) and climate constitute environmental change – the rate of this change compared to other changes over pedological time constitutes a shock. The resilience of the soil is limited by the rate and extent of change we impose compared with the time that soil requires to recover. Soils are resilient to environmental changes and shocks – that is, they will recover from or adjust to change if sufficient 'pedological' time is allowed. The soil management practices that have been applied by humans in a short time frame are unsustainable - a declining soil health threatens human livelihood. The resilience of the soil in terms of human expectations and time frames will depend on its ability to recover to an equilibrium state once improved practices have been extensively applied in order to boost crop production.

Keywords: Soil health, healthier crops, ecosystem, resilience, equilibrium.

INTRODUCTION

Soil health is becoming so important these days as a result of more and more, producers are understanding that healthy soils are more productive and lead to healthier crops. This led to more about sustainable production practices that can help build healthy soil that can sustain the production of healthier crops to the populace. These can be achieved by exploring the on-farm benefits of using cover crops, crop rotation, manure amendments, composting and more on the complex web of life below the surface of the soil in order to improve them.

Soil Management: Soil management encompasses a number of strategies used by farmers and ranchers to protect soil resources, one of their most valuable assets. By practicing soil conservation, including appropriate soil preparation methods, they reduce soil erosion and increase soil stabilization. These soil conservation methods allow for healthy soil formation, soil fertility and favorable soil composition, including soil permeability and soil porosity, which lead to increased soil health. Soil organic matter is a critical component of soil health. Cover crops can help maintain or increase soil organic matter. By using a variety of soil management practices, soil organic matter will increase while soil erosion will decrease, keeping soil nutrients on the farm, which are beneficial to crops grown. Farmers typically use a soil analysis, or soil sampling procedure, to determine what inputs are needed. Key practices include composting, soil chemistry, nutrient mineralization, soil quality/health, organic matter, cover crops, green manures, soil analysis, soil microbiology, soil physics.

Soil properties vary spatially from a field to a larger regional scale as opined by Cambeardella, and Karhen (1999). Such spatial variability and differences in soil fertility within and between farms have considerable effects on resource use efficiency and crop performance. It can help explain significant effects on the spatial distribution of crop yield and quality Tittonel, *et al* (2008).

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.

According to the Environmental Protection Agency (EPA) 2017, agricultural soil management practices can lead to production and emission of nitrous oxide (N2O), a major greenhouse gas and air pollutant. Activities that can contribute to N2O 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. (EPA, 2017). Using biochar may decrease N_2O emissions from soils by an average of 54%, Susan, (2005).

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. Pimentel D,. *et al,*. (2005). Because only 5% of US farmland currently uses no-till and residue mulching, there is a large potential for carbon sequestration, as stated by Lal *et al* (2004). Similar practices such as arable land conversion to grasslands, crop residues and cover crops have been proposed in Europe, Lugato *et al* (2014).

Soil management practices that affect soil quality include:

i. Controlling traffic on the soil surface helps to reduce soil compaction, which can reduce aeration and water infiltration;
ii. Cover crops keep the soil anchored and covered in off-seasons so that the soil is not eroded by wind and rain;
iii. Crop rotations 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;

iv. Nutrient management can help to improve the fertility of the soil and the amount of organic matter content, which improves soil structure and function and

v. Tillage is the breaking of soil, such as with a plough or harrow, to control weeds. 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.

Merits of soil management practices are as follows:

a) Maintain soil fertility;
b) Restore soil fertility;
c) Make the agricultural process an economic one;
d) Help increase yield and
e) Reduce soil erosion

Soil health: Is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. Soil health testing is an assessment of this status. Soil health depends on soil biodiversity (with a robust soil biota), and it can be improved via soil conditioning.

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

a. Sustaining plant and animal productivity and biodiversity (Soil biodiversity);
b. Maintaining or enhance water and air quality and
c. Supporting human health and habitation.

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, Barrow, (1991). The addition of the word "health" shifted the perception to be integrative, holistic and systematic. The two expressions still overlap considerably.

The underlying principle in the use of the term “soil health” is that soil is not just an inert, lifeless growing medium, which modern 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 as expressed by Baskin, (1997) and Paul, (2010). 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. Some microbiologists now believe that 80% of soil nutrient functions are essentially controlled by microbes, Watson, (1992) and Paton, (1978). If this is consistently true, than the prevailing Liebig nutrient theory model, and Mitscherlich modifications of it, all which exclude biology, are perhaps dangerously incorrect for managing soil fertility sustainably for the future.

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

I. In a state of composite well-being in terms of biological, chemical and physical properties;
II. Not diseased or infirmed (i.e. not degraded, nor degrading), nor causing negative off-site impacts;
III. With each of its qualities cooperatively functioning such that the soil reaches its full potential and resists degradation and
IV. 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.

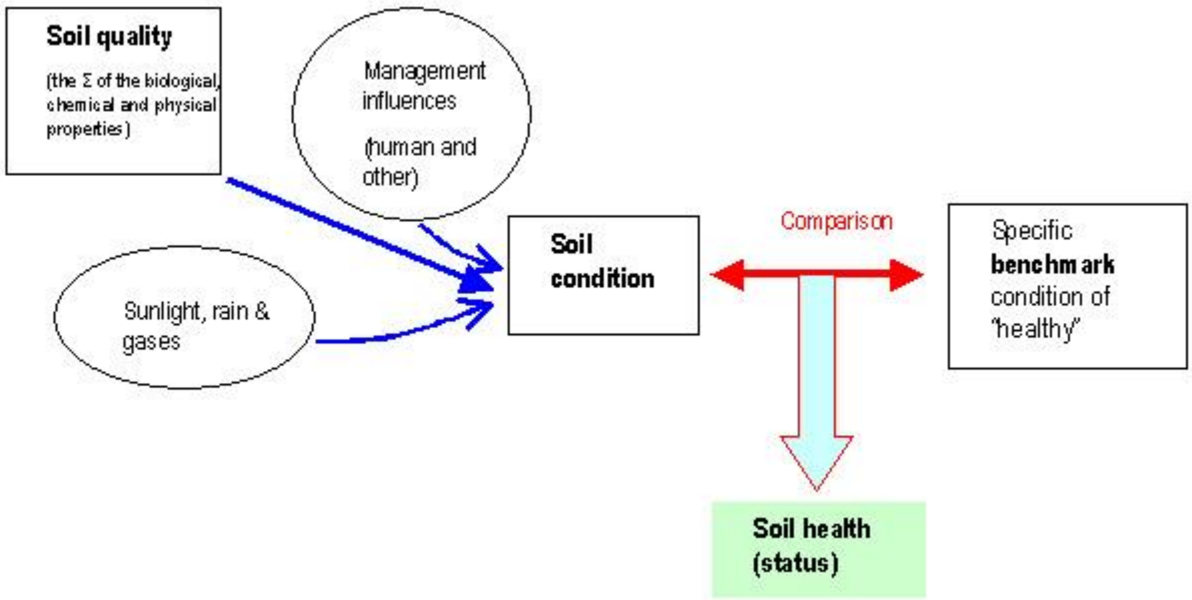
Soil Health is defined as interactive exploration of soil health and how to improve it.

Soil health is so important because more and more, producers are understanding that healthy soils are more productive and lead to healthier crops than the unhealthy ones. It also help in interactive having infographic to learn more about sustainable production practices that can help build healthy soil. Healthy soil can help to explore the on-farm benefits of using cover crops, crop rotation, manure amendments, composting and more on the complex web of life below the surface of the soil.

Soil Management: Soil management encompasses a number of strategies used by farmers and ranchers to protect soil resources, which is one of their most valuable assets. By practicing soil conservation, including appropriate soil preparation methods, they reduce soil erosion and increase soil stabilization.

These soil conservation methods allow for healthy soil formation, soil fertility and favorable soil composition, including soil permeability and soil porosity, which lead to increased soil health. Soil organic matter is a critical component of soil health. Cover crops can help maintain or increase soil organic matter. By using a variety of soil management practices, soil organic matter will increase while soil erosion will decrease, keeping soil nutrients on the farm, Watson, (1992). Farmers typically use a soil analysis, or soil sampling procedure, to determine what inputs are needed. Key practices include composting, soil chemistry, nutrient mineralization, soil quality/health, organic matter, cover crops, green manures, soil analysis, soil microbiology, soil physics.

Conceptualization of a good soil management practices.



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 a point in time.

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:

i. "Productive" options are broad;
ii. Life diversity is broad;
iii. Absorbency, storing, recycling and processing is high in relation to limits set by climate;
iv. Water runoff quality is of high standard;
v. Low entropy; and,
vi. No damage to, or loss of the fundamental components.

This also translates to:

1. A comprehensive cover of vegetation;
2. Carbon levels relatively close to the limits set by soil type and climate;

3. Little leakage of nutrients from the ecosystem;
4. Biological and agricultural productivity relatively close to the limits set by the soil environment and climate;
5. Only geological rates of erosion;
6. No accumulation of contaminants; and,
7. The ecosystem does not rely excessively on inputs of fossil energy

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

Measurements: On the basis of the above, soil health should 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. Lugato *et al* (2014). Soil health testing is spreading in the United States, Australia and South Africa and now in Nigeria. 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 that contains physical (aggregate stability) chemical (mineral balance) and biology (CO_2 respiration) which today are prerequisites for soil health testing. in the United States, six commercial soil laboratories are registered for "Soil Health" testing under the NRCS website. The approach of all the laboratories 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 laboratories.

There is resistance among soil testing laboratories and University scientists to adding new biological tests, primarily since interpretation of soil fertility is based on models from "crop response" studies which match yield to test levels of specific chemical nutrients. These soil test methods have evolved slowly over the past 40 years and are backed by considerable effort. However, in this same time USA soils have also lost up to 75% of their carbon (humus), causing biological fertility to drop drastically. Many critics of the current system say this 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 is reported presently (in the United States) to be the worst it has been since the 1970s, before the advent of environmental consciousness, Baskin, (1997).

Agroecosystems: An agroecosystem is any ecosystem managed primarily for the production of food, fuel or fiber. Agroecology is the study of agricultural ecosystems and the natural resources required to sustain them. Ecological farming requires producers to work within their environmental limitations and use technology to address ecosystem constraints, and gain a competitive edge in the marketplace. Agroecological management enhances the sustainability of agricultural ecosystems by trying to work with the ecological relationships and processes within the broader ecosystem. Agroecology promotes the conservation of soil and organic matter, as well as other resources such as energy and water. Agroecosystems reflect diversity in the landscape, through crop/livestock integration and in marketing. They also seek to strengthen farmers and their communities by developing local agricultural knowledge and building ties among farmers and their consumers.

Cover crop: A common definition of a cover crop is a plant that is used as part of a crop rotation to improve the soil, scavenge or add nutrients, smother weeds and as a tool for erosion control. Cover crops are not harvested, but are left in place in zero tillage, no-till farming or turned under, especially in organic farming. Another term for cover crops is green manures, especially when the crop residue is incorporated into the soil. Cover crops can improve soil fertility and boost crop production by adding organic matter, and they help in nutrient management planning by adding nitrogen to soil or by taking up nutrients in soil after cash crop harvest. Winter cover crops are most common in corn and soybean grain production systems, while spring cover crops or summer cover crops can fit many vegetable production systems. Cover crops improve soil moisture, especially over time as soil organic matter and soil tilth are improved.

Organic farming is an alternative agricultural system which originated early in the 20th century in reaction to rapidly changing farming practices. Organic farming continues to be developed by various organic agriculture organizations today. It relies on fertilizers of organic origin such as compost manure, green manure, and bone meal and places emphasis on techniques such as crop rotation and companion planting. Biological pest control, mixed cropping and the fostering of insect predators are encouraged. In general, organic standards are designed to allow the use of naturally occurring substances while prohibiting or strictly limiting synthetic substances as stated by Paul (2011). For instance, naturally occurring pesticides such as pyrethrin and rotenone are permitted, while synthetic fertilizers and pesticides are generally prohibited. Synthetic substances that are allowed include, for example, copper sulfate, elemental sulfur and Ivermectin. Genetically modified organisms, nanomaterials, human sewage sludge, plant growth regulators, hormones, and antibiotic use in livestock husbandry are prohibited. Danielle, H,. *et al,.* (2013) and Martins, (2014). Reasons for advocation of organic farming include advantages in sustainability, openness, self-sufficiency, autonomy/independence, health, food security, and food safety opined by Gold (2014)

Organic agriculture: It integrates "cultural, biological and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity. can also be defined as; an integrated farming system that strives for sustainability, the enhancement of soil fertility and biological diversity whilst, with rare exceptions, prohibiting synthetic pesticides, antibiotics, synthetic fertilizers, genetically modified organisms, and growth hormones, Helga,. *et al*, (2013) and Paul, (2010).

"Organic and sustainable agriculture often include the use of cover crops, crop rotation, use of tools and machinery for weed and pest management, and conservation tillage. Synthetic fertilizers, sewage sludge, irradiation and genetic engineering may not be used for food to be certified and labelled USDA organic. Organic livestock must have access to the outdoors and be "fed 100 percent certified organic feed, managed without antibiotics, added growth hormones, mammalian or avian byproducts, or other prohibited feed ingredients. Transitioning to Organic Production, addresses conversion strategies, organic farming production practices, marketing approaches and federal organic standards for certified organic crop and livestock. Crop Rotation on Organic Farms reviews shows how rotating crops improve soil quality and health and help manage pests, diseases, and weeds.

Soil organic matter: Consists of three distinctly different parts—living organisms, fresh residues, and well-decomposed residues. These three parts of soil organic matter have been described as the living, the dead, and the very dead. A typical agricultural soil has 1% to 6% organic matter. The benefits of organic matter include improved soil structure, increased infiltration and water-holding capacity, increased cation exchange capacity, and more efficient long-term storage of plant nutrients. Without organic matter, you have no soil to speak of, only a dead mixture of ground-up and weathered rocks. Two comprehensive tools to help one build soil organic matter and healthy soil are building soils for better crops and managing cover crops for the profitably of man.

Soil quality/health: The living part of soil organic matter includes a wide variety of microorganisms, such as bacteria, viruses, fungi, protozoa, and algae. It even includes plant roots and the insects, earthworms, and larger animals, such as moles, woodchucks, and rabbits that spend some of their time in the soil. The living portion represents about 15% of the total soil organic matter.

Farmers and ranchers use the term soil health to describe the condition of the soil. Scientists usually use the term soil quality, but both refer to the same idea — how good is the soil in its role of supporting the growth of high-yielding, high-quality, and healthy crops? Healthy soil generates higher crop yields, it absorbs and holds rainfall, and erosion is therefore reduced.

Crop rotation: The use of diverse soil management practices, composting, and cover crops all contribute to healthy soil by conserving and building soil organic matter, absorbing rainfall, and retaining crop residues on the soil surface. Major conservation practices include conservation tillage, contour farming, strip cropping, terraces, diversions, and grassed waterways.

Soil consists of four parts: mineral solids, water, air, and soil organic matter. All four are important characteristics of fertile soil.

Soil resilience: Refers to the ability of a soil to resist or recover their healthy state in response to destabilizing influences. This is also termed as a subset of a notion of environmental resilience. Soil resilience should first be looked at in terms of soil formation and development (pedogenesis), a continuous process taking thousands of years – this puts into context the short time that humans have so extensively utilized, changed and depended directly on soil. Pedogenesis is the result of five factors: the first two are parent material and topography, which are passive and contribute to soil mass and position; the next two are climate and the biosphere, which are active and supply the energy in soil formation and finally, time.

It is the active factors in soil formation that vary so as to constitute an environmental change or shock. Over time, variations have been significant due to:

a. Over millions of years the soil has endured varying atmospheric conditions including a complete absence of oxygen and associated behavior of soil elements in a reducing environment, and the establishment of life - particularly of terrestrial vegetation 420 million years ago.
b. Over ten thousand years and following the last ice age, though average climate has remained relatively stable, the soil has faced periods of extended wet, dry and fire.

If soil were not resilient, then in the face of past influences it would not be in any condition to support the natural and commercial services that we expect of it currently. So what do we expect of soil resilience are:

1. Constant or evolving state - Do we expect that the soil to remain constant – to continue to provide the same environmental and commercial services as at present, or; that it will establish a new equilibrium?
2. How long will it take - How long do we expect soils to ‘hold out’ or adjust, and are we realistic about pedological time?

In Nigeria and other African countries, the above questions are relevant given the strong dependence on the soil, yet the significant degradation of soils over little more than 200 years due to adoption of modern styled agriculture. This is in the context of the real prospect of climate change, cyclical drought and other degrading affects.

It is in the interest of humans to sustain soils as this is the essence of our existence: the maintenance of fertile soil is “one of the most vital ecological services the living world performs”; the “mineral and organic contents of soil must be replenished constantly as plants consume soil elements and pass them up the food chain”.

It is claimed by Watson (1992) that the ecosystems of Australia, which have evolved over millennia, have been decimated over the last 200 years. The expectation has been one of ongoing environmental and commercial service, yet the practices applied have been unsustainable and have led to such soil related problems as salinity, acidity, nutrient decline, erosion and structure decline.

Barrow (1991) claims that despite decades of humans talking of an impending environmental crisis, including the breaking point of our soils’ fertility, threats to the environment have continued to grow faster than the willingness to control them. Even with good intentions and best farming practices, still we are caught out by drought and wet periods, which cause unsustainable degradation.

The pressure that we impose on the soil in terms of biosphere (direct human impacts included) and climate constitute environmental change – the rate of this change compared to other changes over pedological time constitutes a shock. The resilience of the soil is limited by the rate and extent of change we impose compared with the time that soil requires to recover.

Soils are resilient to environmental changes and shocks – that is, they will recover from or adjust to change if sufficient ‘pedological’ time is allowed. The soil management practices that have been applied by humans in a short time frame are unsustainable - a declining soil health threatens human livelihood. The resilience of the soil in terms of human expectations and time frames will depend on its ability to recover to an equilibrium state once improved practices have been extensively applied in order to boost crop production.

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