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Soil Health Management and Sustainability

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Introduction

Soil health has been defined by Doran and Zeiss as “the capacity of a soil to function as a vital living system within ecosystem and land use boundaries to sustain plant and animal production, maintain or enhance water and air quality, and promote plant and animal health.” Soil health is an intrinsic characteristic of a soil. It is recognized as a list of characteristics that define its health and place it taxonomically. Soil quality, conversely, is an extrinsic characteristic of soils and changes with the desired use of that soil by humans. It may relate to agricultural output and capacity to support wildlife, to protect watershed, or provide recreational outputs. The rapid projected increase in world population to 8.9 billion people by 2050 will lead to higher demands for agricultural products. High food demands and the shortage of new agricultural land development in the future will require doubling crop yields using sustainable means. Scientists can make a substantial contribution to global sustainability of the agricultural lands by translating scientific knowledge on soil function into practical methodologies that enrich grower’s knowledge to evaluate the sustainability of their management practices. Two sustainable agricultural management strategies are targeted to increase soil organic matter and reduce erosion through improvements in plant diversity and conservational tillage. Meeting the projected demand for healthy and sustainable food production is a crucial challenge. In fact, increasing crop productivity by mitigating climate Change and preserving agro ecosystems is one of the significant goals of sustainable agriculture.

Soil Biodiversity and Sustainability

Soil biodiversity refers to all organisms living in the soil. The Convention on Biological Diversity defined the soil biodiversity as “the variation in soil life, from genes to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes”. Increasing human populations, global climate change, soil degradation, and loss of productive agricultural lands have been shown to increase

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the pressure on natural resources and threaten processes that maintain global sustainability. Soil microorganisms connect roots with soil, recycle nutrients, decompose organic matter, and respond quickly to any changes occurring in the soil ecosystem, acting as accurate indicators for specific functions in the soil environment. Microbial community functions and their relation with the soil and plant can establish a sustainable soil ecological environment for supporting crop growth, development, and long term yields. Therefore, an understanding of microbial communities' functions, behavior and communication processes in soil and plants are critical for prevention of unexpected management practices before onset of non-repairable damage in the agro ecosystem. In fact, understanding microbial activities will provides consistent diagnostics of sustainable soil health and crops production.

Soil Health Components for Sustainable Agriculture

Soil health and soil quality are terms used interchangeably within the scientific literature and some. Believe that they are synonymous functionally. However, the term soil quality is preferred by the scientists while farmers prefer soil health. Ritz et al. Identified and screened 183 biological indicators for monitoring soil. The most common biological indicator candidates were:

1) Soil microbial taxa and community structure using terminal restriction fragment length polymorphism techniques,
2) Soil microbial community structure and biomass using extracted lipids, in particular phospholipids fatty acids, as signature lipid biomarkers,
3) Soil respiration and C cycling from multiple substrate-induced respiration,
4) Biochemical processes from multi-enzyme profiling,
5) Nematodes, including maturity index (the distribution of nematodes across functional groups), taxa number, and abundance of individual functional groups,
6) micro arthropod,
7) On-site visual recording of soil fauna and flora,
8) Pitfall traps for ground-dwelling and soil invertebrates, and microbial biomass, the total quantity of life belowground.

Healthy soil was shown to suppress pathogens, sustain biological activities, decompose organic matter, inactivate toxic materials and recycle nutrient, energy, and water. Karlen *et al.* Defined soil quality as "the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Further, a broader defining view to soil quality was provided by Bouma et al. as "the intrinsic capacity of a soil to contribute to ecosystem services, including biomass production." The concept of soil quality allows practical applications with regards to targeted ecosystem services. Soil quality is an increasingly popular concept that encompasses soil biological characteristics and functions in close interaction with chemical and physical properties. As previously indicated, the terms "soil quality" and "soil health" are used as synonymous in the literature. However, "soil health" indicates condition of soil in a short period and "soil quality" over a longer period, much analogous to the condition of a human at a particular time (health) and long time period (quality of life). Soil health and soil quality terms were used as measurements of soil status, and their assessment is aimed to monitor the influence of present, past, and the future of land use on agricultural sustainability.

System management and soil health

Soil management practices that protect soil health are not only economically and environmentally necessary but the right approach to sustain and increase soil resiliency . This can be achieved by adopting conservation plans that are practical, site specific and an integral component of the overall agriculture production system to achieve intended objectives. These Conservation plans would include no-tillage and reduced tillage (i.e., strip-tillage), which leave post-harvest crop residue to cover the soil surface. In addition, many soil conservation plans include practices such as cover crops, the construction of grass waterways, terraces, buffer strips and pasture erosion control systems with manure application and soil testing. Conservation planning and implementation need to be carefully considered as a solution to reducing potentially negative impacts of row cropping systems on soil and water quality. Consideration of site specifics and the objectives of implementation should be included in the planning process. Finally, the system approach to conservation must include nutrient loading and sediment reduction plans as effective measures to protect soil and water quality.

Crop residue and cover crops management for healthy soils

Cover crops after harvest can be essential component along with crop residue to improve soil health through the reduction in soil erosion, improvement of soil structure and enhancement of soil organic matter . The combination of both crop residue and cover crops can have additional benefits in reducing nutrients loss by reducing surface runoff, especially early in the growing season, where the soil is most vulnerable for lack of significant canopy cover and the exposure of the bare soil surface to rain events. The importance of cover crops had been overlooked since 1960 as a component of the production system for nutrient input due to the availability and affordability of chemical fertilizers. The current emphasis on cover crops in the past decade or two is driven by the environmental challenges associated with row cropping systems. Climate variability has magnified the challenge especially where soils are exposed to weather conditions without physical protection, coupled with the intensity of tillage, which accelerates both soil erosion and water quality deterioration. The benefits of cover crops include protecting the soil from excessive dryness to prevent cracks and fractures at the soil surface, thus improving soil water storage, soil microbial community, nutrient cycling and uptake by plants, the reduction of soil erosion during rain events and sediment loss. Cover crops increase water storage by reducing evaporation and increasing water infiltration, which is an important outcome for agriculture systems in dry and semi-dry regions. Reduction in evaporation from soil surfaces occur if the cover crop is left on the soil surface as mulch. The best protection against moisture loss and wind erosion is a good protective cover of growing plants and plant residue. The value of cover crops and residue as components of conservation systems such as no-tillage or strip-tillage can have great impact on increasing soil organic carbon and its contribution to increase water storage.

Integrated approach for building soil health

The integration of different components in managing conservation agriculture systems is essential for optimizing soil biological and physical functions. The performance of conservation systems such as no tillage for example, showed a wide range of outcomes in improving soil health, ecosystem services, and productivity. The limitation and uncertainties of conservation agriculture (CA) can be addressed through careful planning and consideration of certain process that will help in achieving successful outcomes. Some of the main considerations that can be valuable in reducing the limitations or constraints associated with CA include, but not limited to the following:

1. Careful planning for implementing the intended CA system and the consideration of site and regional specific constraints to achieve goals of the CA system. These conditions include soil type, drainage class, topography of landscape, and climate conditions particularly in the Midwest,

where humid and sub-humid weather conditions are dominant.

2. Selection of a suitable tillage system such as no-tillage or strip-tillage that is appropriate for site- or region-specific conditions, as essential parts of the CA system to minimize the productivity and environmental constraints to the system. In these two systems (no-tillage and strip-tillage) a specific management practice such as residue management is essential to reduce the effects of cold soil temperatures on plant germination early in the spring.
3. Proper implement attachments such as residue cleaners and combine calibration during harvest to ensure uniform residue distribution for optimum management of the selected tillage system. These considerations can optimize soil conditions such as soil temperature through proper management of crop residue (residue managers/wipers) for uniform plant stand.
4. Selection of cropping systems (i.e., crop rotations) that sustain soil and improve soil functions (physical, biological, and chemical properties), sustain productivity, and enhance environmental quality. These attributes need to be balanced with the economic viability of the systems. The mono cropping system (i.e., continuous corn) has been documented to be unsustainable economically and in productivity even with the best soil conditions.
5. Sustainability of nutrient management programs through careful seasonal assessment that ensure adequate nutrient supply to the plants for optimum grain yield and biomass production for replenishing soil organic matter and enhancing microbial biodiversity.
6. Well planned management operations that will minimize soil compaction by rethinking implement design and timing of operations to help reduce the random travel on field for traffic control to improve soil structure. The consideration of soil moisture conditions is essential to reducing soil compaction during planting, improper seed depth, and side-wall compaction resulting during planting in high soil moisture conditions. Soil compaction, which has negative effects on soil structure and its associated potential to increase surface runoff, is a significant factor in yield reduction.
7. Proper timing of field operations at appropriate moisture conditions (at or below field capacity) for fertilizer application, weed, pest and disease control, and harvest. A major challenge with any management system is its proper timing to achieve desired outcomes.

Promote climate-smart soil and land management

To address future challenges to food security and achieve the sustainable development goals, climate-smart agriculture must be made operational. Climate-smart agriculture is an umbrella term that includes many approaches built on geographically specific solutions, such as no-till farming, fertilizer deep-placement technology, and integrated soil fertility management. The

Concept embraces three pillars:

1. Sustainable increases in productivity.
2. Enhanced resilience and adaptation of farming systems.
3. Mitigation of GHG emissions

Conclusion

This review examined the role of soil health in intensive crop production systems and identified Factors to consider when assessing soil health components in sustainable agricultural systems. Soil health considers soil biota component such as microorganism abundance, diversity, activity, and community stability. The diversity and abundance of soil and rhizosphere microorganisms influence plant composition, productivity, and sustainability. AMF enhance water use efficiency and nutrient availability to plants. Cyanobacteria adapted to a wide range of harsh environmental conditions, represent a consistent renewable biomass source of soluble organic matters known as secondary metabolites, acting as a growth promoters and supporting agricultural crop productivity. The soil profile contains several types of harmful and beneficial nematodes. Harmful nematodes feed on plant roots and reduce their productivity; while beneficial nematodes play a key role in soil nutrient cycling for better soil health. Organic system increases soil nutrient mineralization, and microorganism abundance and diversity as well as soil physical properties. Interestingly, organic fertilizer source (plant- or animal-based) can potentially affect microorganism abundance and crop yield. While plant-based fertilizer increases soil microbial abundance, animal-based fertilizer has higher crop yield and lower number of microorganisms. However, organic cultural practices are more costly due to high labor cost and lack of uniformity and stability of organic fertilizers. Overall, plant-based farming can be an ideal practice to increase soil and fruit quality, while animal-based fertilizer would be the preferred for organic farmers seeking higher yield at relatively lower input cost of fertilizers. For tillage practices, conservation tillage (no-tillage, reduced, and strip) improve soil health by enhance soil fungi abundance and activity, earthworm diversity, organic matter, aggregate stability, and caution exchange capacity. In fact, conservation tillage such no-till reduced irrigation water applied (12–25%) and increased water use efficiency (16–24%) and total net returns ($49–281) compared to conventional (e.g., mould board, harrow followed with cultivator). However, conservation tillage might increase root-feeding nematodes (harmful to plant roots) compared to conventional. Improved assessment of soil health indicators is necessary to further enhance our understanding on how production strategies and environmental factors affect the physical, biological, and chemical stability and dynamics of the soil-rhizosphere-plant systems and their impact to short or long term sustainability.