9. Good Agricultural Practices for Soil Health and Carbon Sequestration

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Carbon is found in all living organisms and is the major building block for life on Earth. Carbon exists in many forms, predominately as plant biomass, soil organic matter, and as the gas carbon dioxide (CO_2) in the atmosphere, and dissolved in seawater. Soil is a large reservoir of carbon, with about 60% organic carbon in the form of soil organic matter (SOM), and the remaining inorganic carbon in the form of inorganic compounds (e.g., limestone, or $CaCO_3$). It is estimated that SOM stores about twice as much carbon as the atmosphere, and about three times as much as forests and other vegetation. Soil carbon sequestration is the removal of CO_2 from the atmosphere through plant photosynthesis, and storage as long-lived, stable forms of soil organic matter that is not rapidly decomposed (Lal, 2008). Changes in soil organic carbon levels can have significant effects on atmospheric CO_2 levels.

How is carbon sequestered in soils?

Through the process of photosynthesis, plants assimilate carbon and return some of it to the atmosphere through respiration. The carbon that remains as plant tissue is then consumed by animals or added to the soil as litter when plants die and decompose. The primary way that carbon is stored in the soil is as soil organic matter (SOM). SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and carbon associated with soil minerals. Carbon can remain stored in soils for millennia, or be quickly released back into the atmosphere. Climatic conditions, natural vegetation, soil texture, and drainage all affect the amount and length of time carbon is stored. In agricultural systems, the amount and length of time carbon is stored is determined predominately by how the soil is managed. A variety of agricultural practices can enhance carbon sequestration in soils. The benefits of these practices as well as their potential hidden costs must be considered when management decisions are made. Though not discussed here, there may also be direct or indirect monetary costs and benefits to farmers to implement these techniques.

Benefits of carbon sequestration

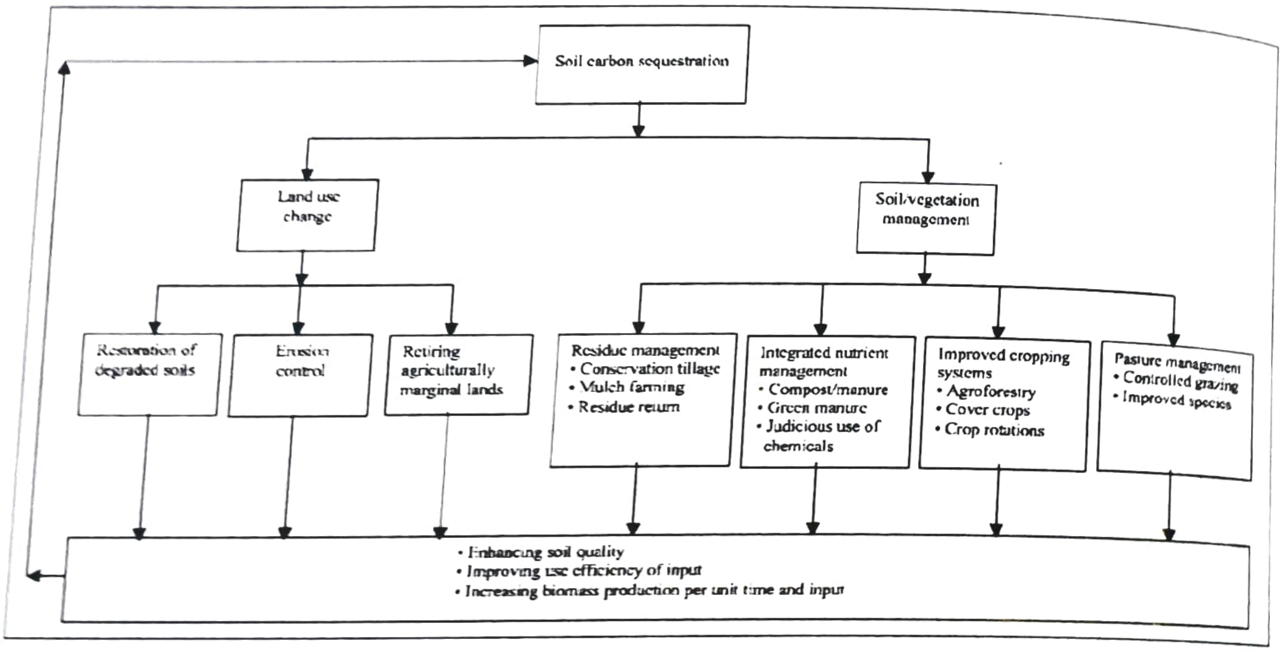
In addition to reducing current atmospheric CO_2 levels, increasing soil carbon sequestration can provide other benefits for soil health, the environment, and crop production:

- Improved soil structure
- Increased soil fertility

- Increased infiltration capacity
- Increased water holding capacity
- Increased water use efficiency
- Improved soil health resulting in higher nutrient cycling and availability
- Reduced fertilizer (N, P) needs over the longer term
- Increased agricultural productivity and profitability

Management practices for soil carbon sequestration

A wide range of the good agricultural practices exist for sequestering organic carbon in agricultural soils. Appropriate practices differ for different soil, crop, and climate conditions. A site-specific approach should be used to select the most appropriate practice to meet local needs by considering all inputs and benefits/costs associated with each input. A life-cycle analysis that considers inputs and associated environmental and economic benefits needs to be carried out. For example, no-till or minimum-till has been identified as one of the best practices to sequester soil organic carbon. However, it may require use of herbicides, which have both environmental and economic implications.



Strategies for soil carbon sequestration

The following management practices can increase soil carbon sequestration and help mitigate climate change.

Addition of organic soil amendments such as compost, animal manure, biosolids

Manure inputs increase soil organic carbon. Continued input is required in order to maintain higher soil organic carbon level. Once the addition stops, much of the carbon "sequestered" in the soil may be lost due to decomposition. Some residual benefits from manure addition, however, may last for long periods, as improved soil conditions increase productivity and plant residue input into the soil.

The quality of organic carbon inputs is important for soil carbon sequestration. The conversion efficiencies of manure are almost twice that of plant residues. In other words, for constant rates of addition, net soil organic carbon accumulation from manure is nearly twice of that from plant residue additions. It is postulated that the slower decomposition of manure in soils results from the fact that manure consists of largely partially decomposed products. Similarly, products of aerobic composting and anaerobic digestion are also expected to have higher efficiencies for increasing soil organic carbon content than plant materials.

There is an important implication from these results. Soil organic carbon levels have generally decreased upon cultivation. This is partly because of the increased decomposition of soil organic carbon resulting from tillage and partly because of the decreased inputs as a result of the removal of above ground plant biomass. If the above ground biomass is used in animal production and manure is returned to the soil, what is the implication for long-term soil organic carbon sequestration? Approximately one half of the carbon in the animal feed is present in the manure. Since manure is nearly twice as efficient in storing organic carbon in soils, one thus naturally concludes that in an animal production system, if manure is returned to the soil, it will be as effective in maintaining soil organic carbon level as in a natural system in which most of the plant biomass is returned to the soil.

Reduced tillage

Increased soil organic carbon decomposition from tillage is one of the major factors responsible for the decrease in soil organic carbon content upon cultivation. As a result, avoiding tillage has generally been reported to increase soil organic carbon content. Reducing tillage intensity minimizes or eliminates manipulation of the soil and leaves crop residues on the soil surface. These procedures generally reduce soil erosion, improve water use efficiency, and increase carbon concentrations in the topsoil. Reduced tillage can also reduce the amount of fossil fuel consumed by farm operations. It has been estimated to have the potential to sequester a significant amount of CO_2.

Cover cropping

Cover cropping is the growing of soil covering crops such as mucuna, horsegram for protection and soil improvement between periods of regular crop production. Cover crops improve carbon sequestration by enhancing soil structure, and adding organic matter to the soil.

Crop rotation

Crop rotation refers to growing a sequence of crops in regularly recurring succession on the same area of land. It mimics the diversity of natural ecosystems more closely than intensive monocropping practices. Varying the type of crops grown can increase the level of soil organic matter. However, effectiveness of crop rotations depends on the type of crops and crop rotation times.

Enhancing biological N fixation through the use of legume crops

Increasing crop yields increases plant residue input into the soils and thus has the potential of increasing soil organic carbon level. Further, for each legume crop grown, there is approximately 1 ton of CO_2-C emission that is avoided in terms of savings on N fertilizer whose manufacture involves fossil fuel burning. The carbon emission savings from using legume plants is permanent while soil carbon content increase resulting from increased inputs must be maintained continuously.

Including crops/varieties with higher root biomass in the cropping system

There is reason to believe that most of the carbon sequestered in soil originates from roots (Rasse *et al.,* 2005). By virtue of its inherently low decomposability, and their much more intimate interaction with soil particles and aggregates, root carbon has greater opportunity for being sequestered in soil in stable form that carbon applied through plant residues or manures (Srinivas, 2017). Inclusion of crops/varieties with greater root biomass and management practices that encourage better root growth, especially in deeper soil layers can lead to considerable carbon sequestration in soil.

Avoiding fallow

Fallowing significantly increases the rate of soil organic carbon decomposition. Research results indicate that during fallow the rate of soil organic carbon decomposition is approximately 2 to 2.5 times faster than in a crop year. Thus, to maintain soil organic carbon level, if the fallow frequency is once every two years, the organic carbon input must be 1.5 times higher than in a system with no fallow. As a result, the fallow treatment often results in significantly more soil organic carbon loss than continuously cropped treatment.

Application of recommended doses of nutrients

The application of adequate nutrients through integrated nutrient management ensures greater crop production, greater root growth and greater availability of biomass for recycling. Long term experiments consistently show improvement in soil organic matter with application of recommended doses of nutrients through integrated nutrient management.

Biochar

Biochar is a microbially resistant carbon substance which is produced by heating organic wastes such as crop residues or wood chips in the absence of oxygen by a process called pyrolysis. Ordinary biomass fuels are carbon neutral; the carbon captured in the biomass by photosynthesis is eventually returned to the atmosphere through natural processes like decomposition. Sustainable biochar systems can be carbon negative by transforming the carbon in biomass into stable carbon structures in biochar which can remain sequestered in soils for hundreds and even thousands of years.

Conventional and corresponding improved practices for sequestering carbon in soils

Conventional practice	Carbon sequestering practice
Biomass burning	Residue use as soil cover
Tillage and clean cultivation	Reduced tillage, surface residue
Fallow	Cover cropping
Monoculture	Diversified cropping system – crop rotation/ intercropping/ mixed cropping
Low input/subsistence farming	Judicious use of inputs
Intensive chemical fertilizer use	Integrated nutrient management
Intensive cropping	Integrtaed farming system with crops, trees, livestock
Surface flood irrigation	Subsurface/drip/sprinkler irrigation
Cultivation of marginal soils	Conservation reserves/Plantations for restoring degraded lands

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