

Soil carbon sequestration through farming practices

a carbon-negative technique to reduce global warming

Tarun Paul¹, Koushik Banerjee², Partha Sarathi Patra³, Kousik Nandi⁴ and Suchitra Roy⁵

Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal 736 165

Widespread exploitation of natural resources resulted in many concomitant environmental hazards out of which global warming is utmost important. Rise in Green House Gases (GHGs) concentration especially CO₂ in the atmosphere, causes global warming. Agriculture accounts for about 14% of global GHGs or about 6.8 Giga tonnes of CO₂ equivalents per year. Agricultural activities serve as both source and sink for GHGs. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process known as carbon sequestration. Carbon sequestration involves innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, agroforestry system, microbial sequestration, biochar etc. which trap CO₂ from the atmosphere. Soil carbon sequestration off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term crop productivity.

Key words: Farming practices, Global warming, Soil carbon sequestrations

NATURAL resources are being exploited extensively world-wide with increase in human population. This has resulted in many concomitant environmental hazards out of which global warming is of utmost important. Increase in Green House Gases (GHGs) concentration, especially CO₂ in the atmosphere, causes Green House Effect, i.e., warming of the earth atmosphere. Agriculture accounts for roughly 14% of global GHGs or about 6.8 Giga tonnes of CO₂ equivalents per year. Thus, there is emphasis to reduce this concentration through the process known as carbon sequestration an important cost effective tool for mitigating global warming. Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other

organic solids, and in a form that is not immediately reemitted. Agricultural activities serve as both source and sink for greenhouse gases. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process of carbon sequestration. Innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, agroforestry system, microbial sequestration, biochar etc. trap CO₂ into soil from the atmosphere. This transfer or “sequestering” of carbon helps off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term crop productivity.

Global carbon cycle

Carbon concentration in environment and the global carbon pool is mainly governed by Carbon Cycle. During photosynthesis carbon from atmosphere gets fixed and

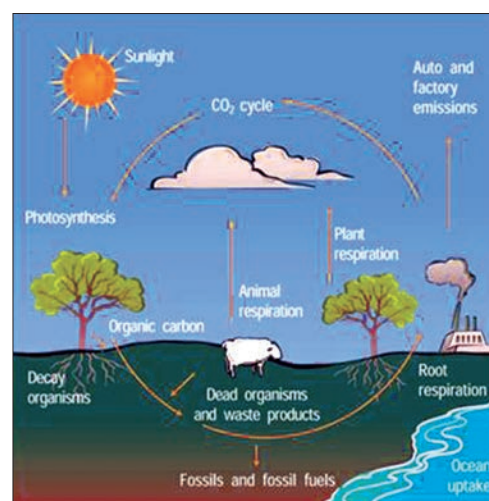


Fig. 1: Global carbon cycle

assimilated by plants. Some of this assimilated carbon returns to atmosphere as CO₂ through plant respiration and other part is distributed into above ground biomasses which are taken up by herbivores, from where carbon is cycled in every stratum of food chain and food pyramid and ultimately lost to atmosphere as CO₂. Carbon also gets added to soil through root exudates, leaf litters, plant residues where it faces the transformation such as immobilization in tissues of soil biota and mineralization resulting in release of carbon as CO₂ into atmosphere (Fig. 1).

Why soil carbon sequestration?

- It increases soil organic matter content
- It increases water holding capacity of soil
- It increases nutrient holding capacity in turn improves nutrient reserves
- It improves aggregate stability of soil structure
- It increases plant biomass and improves soil biodiversity
- It improves root growth, over all plant growth and in turn increases yield.

Farming practices of soil carbon sequestration

- Conservation agriculture practices
- Cropping sequence
- Efficient nutrient management
- Organic farming
- Dryland farming
- Arbuscular mycorrhizal fungi
- Plant root sequestration
- Biochar application
- Agroforestry
- Forest management practices.

Conservation agriculture and C-sequestration

Conservation agriculture aims to achieve sustainable and profitable agriculture and subsequently aims at improved livelihood of farmers through the application of the three principles: (i) Minimal soil disturbance, (ii) Permanent soil cover, and (iii) Suitable crop rotation. Conservation agriculture makes use of soil biological activity and cropping systems to reduce the

excessive disturbance of the soil and to maintain the crop residues on the soil surface in order to minimize damage to the environment and provide organic matter and nutrients. Conservation agriculture aims to provide and maintain optimal conditions in the root zone in order to enable them to grow and function effectively without hindrance in capturing plant nutrients and water; excess water passes through soil to groundwater and stream flow, not over the surface as runoff where it can cause erosion.

Importance of conservation agriculture:

- Maintain and rebuild soil architecture for enhanced water entry and distribution within the soil profile,
- Compete with soil pathogens,
- Contribute to decomposition of organic materials to soil organic matter and various grades of humus, and
- Contribute to the capture, retention and gradual release of plant nutrients.

The above attributes helps in avoid physical or chemical damage to roots and soil organisms that would disrupt their effective functioning.

Cropping sequence and C-sequestration

Soils under natural vegetation capture more atmospheric CO₂ compared with fallow soil. It is necessary to include crops and pastures in the rotation that add large quantities of biomass in the soil. Even more C can be stored by adding leguminous cover crops to the rotation. Besides addition of C to the soil, legumes add a substantial quantity of N to the soil, which results in increased biomass

production of succeeding crop.

Integrated nutrient management and C-sequestration

Balance fertilization improves soil C sequestration than imbalance use of fertilization. Integrated use of inorganic and organic sources of nutrients along with biofertilizers increase biomass yield and improves aggregate stability of soils. Micronutrients such as zinc, boron, iron and molybdenum are deficient in Indian soil. Therefore, balanced fertilization is the urgent need to restore soil fertility (Table 1).

Organic farming and C-sequestration

Organic farming encompasses the use of inputs from organic sources such as use of compost, FYM, vermicompost, biofertilizer, biopesticides, etc. A long-term study showed that soil carbon significantly increased with organic practices, while conventional system showed no significant increases in either soil carbon or nitrogen. Organic practice use less fossil fuel, resulting in an additional reduction of CO₂ released into the atmosphere.

Dryland farming and C-sequestration

Drylands occupy approximately 43% of the Earth's surface with 70% of dryland agricultural soils subject to degradation and desertification. Almost two billion people, most of them poor farmers, depend on agricultural production on marginal and degraded soils for their livelihood. Globally drylands have a potential for carbon sequestration of 12-18 Pg C through desertification control. Over half of the farming population of India live in semi-arid regions. Irrigation and inorganic

Table 1. Soil C sequestration through integrated nutrient management

Location	Soil	Cropping system	Initial SOC (g/kg)	SOC after 20 years (g/kg)		
				Control	NPK	NPK+ FYM
Bhubaneswar	Inceptisol	Rice-rice	2.7	4.1	5.9	7.6
Pantnagar	Mollisol	Rice-wheat	14.8	5.0	9.5	15.1
Pantnagar	Mollisol	Rice-wheat-cowpea	14.8	6.0	9.0	14.4
Faizabad	Inceptisol	Rice-wheat	3.7	1.9	4.0	5.0
Barrackpore	Inceptisol	Rice-wheat-jute	7.1	4.2	4.5	5.2
Palampur	Alfisol	Maize-wheat	7.9	6.2	8.3	12.0
Karnal	Alkalisoil	Fallow-rice-wheat	2.3	3.0	3.2	3.5
Nagpur	Vertisol	Cotton-wheat	4.1	—	—	5.5
Trivandrum	Ultisol	Cassava	7.0	2.6	6.0	9.8

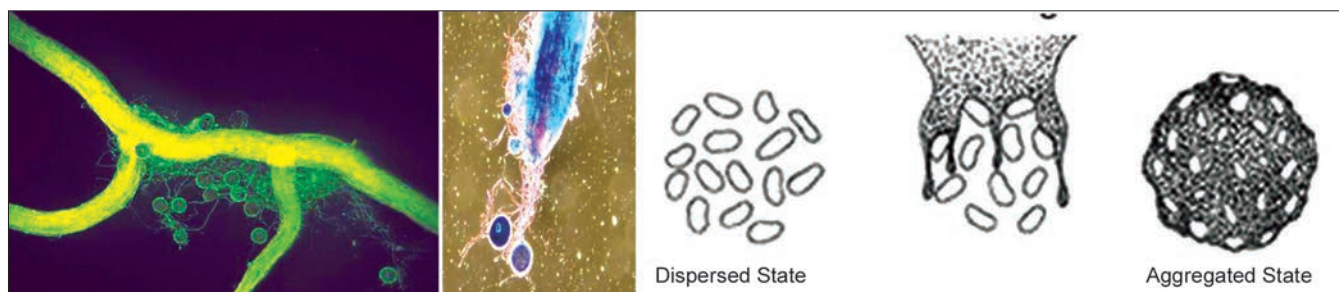


Fig. 2: Glomalin produced by AM fungi binding soil particles

fertilizers are expensive and inaccessible for the rural poor. Soil fertility treatment using legume cultivation and vermicompost production are increasingly used, leading to increased organic matter. Meanwhile, the use of inorganic fertilizers and the continuous cultivation of cereals lead to a substantial decline in soil carbon levels. The use of farmyard manure, green manure, vermicompost and plant residues increases soil carbon. Agroforestry practices substantially increased soil carbon by 0.9 t C/ha/year. Leguminous crops also have beneficial effects when included in rotations.

Arbuscular mycorrhizal fungi and C-sequestration

Fungi aggregate organic matter with clay and minerals, making it more resistant to microbial degradation. It produces glue like substance called Glomalin which is a recalcitrant glycoprotein. Glomalin contributes to the stabilization of aggregates by sloughing off hyphae onto the surrounding organic matter, binding clays through cation bridging by iron and providing a hydrophobic coating.

Not only does glomalin contain 30-40% carbon, but it also forms aggregates that add structure to soil and keep other stored soil carbon from escaping. The only producers of glomalin are

arbuscular mycorrhizal fungi, which are found living on plant roots around the world. The arbuscular mycorrhizal relationship commonly referred to as endomycorrhizae occurs with approximately 80% of the world's plants species in their native habitat. Glomalin production is increased with increased mycorrhizal colonization a contributing factor to the increase in soil carbon. Soils and perennial grasses are a potentially powerful sink for accumulating carbon in soil organic matter when mycorrhizal fungi are present.

Plant roots sequestration

Plant roots have ability to synthesize, accumulate and secrete a diverse array of compounds. More than 200 carbon compounds released from plant roots in the form of exudates are reported, which is

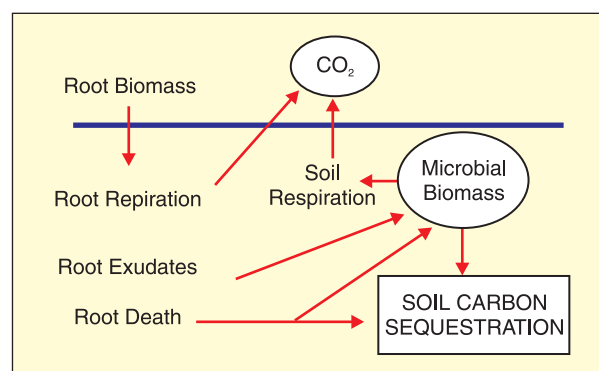


Fig. 3: Carbon sequestration in soil via plant roots.

termed as rhizodeposition. These exudates contain simple water-soluble compounds such as amino acids, organic acids, sugar and various plant secondary metabolites to complex polymeric compounds such as polysaccharides, polypeptides and enzymes. Fig. 3 reveals the pathway of carbon transfer from biosphere towards the rhizosphere. Carbon is added in the soil system by plant roots through root death, root exudates and root respiration. Metabolically active respiring roots are responsible for exudation and respired CO_2 . However, non-

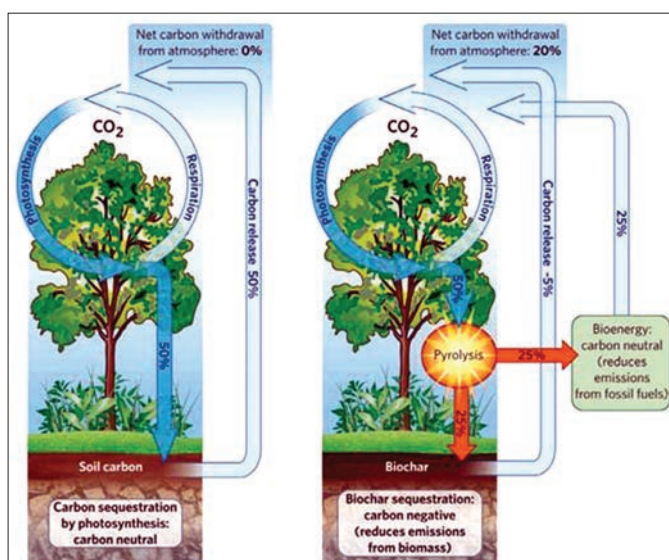


Fig. 4.a: Summary of pyrolysis process



Fig. 4.b: Biochar of rice husk

metabolically active roots release carbon in its soluble form, which is termed as *lysis*.

Biochar application and C-sequestration

Biochar is a fine-grained and porous charcoal like material produced by pyrolysis of biomass in oxygen limited condition. It acts as atmospheric carbon sink. The definition adopted by the International Biochar Initiative furthermore specifies the need for purposeful application of the material to soil for agricultural and environmental gain. Biochar is 'Carbon Negative'. In case of natural carbon sequestration by photosynthesis 50% of assimilated carbon returns to the atmosphere as CO₂ through respiration and rest 50% gets added to soil through plant biomass, root, etc. After some period of time this total amount which was added to soil, return to the atmosphere as CO₂ through mineralization of organic matter and respiration of roots and soil biota. So, in this case the net removal of carbon from atmosphere is 0%. In comparison to this system, in case of biochar sequestration, the rest 50% of assimilated carbon is not directly added to soil, rather those amount undergoes pyrolysis where 25% of the carbon is released for production of biofuel and synthesis gas which are carbon negative and can be used for power generation and fuel substitute. The rest 25% carbon of pyrolysed biomass when gets added to soil, remain there for longer period of time due to their recalcitrant nature resulting in slow mineralization causing release of only 5% carbon as

compared to atmosphere. Net removal of carbon from atmosphere is 20%. That is why biochar system is 'Carbon Negative' (Fig. 4.a and 4.b).

Agroforestry system and C-sequestration

Agroforestry system is recognized as a carbon sequestration strategy because of its applicability in agricultural lands as well as in reforestation programmes:

Direct role: Carbon sequestration rates ranging from 1.5 to 3.5 Mg C/ha/year in agroforestry systems

Indirect role: Agroforestry has some indirect effects on C sequestration since it helps to reduce pressure on natural forests

IPCC Report estimated the area currently under agroforestry world wide is 400 million ha with an estimated carbon gain of 0.72 Mg C/ha/year. At a global scale, it has been estimated that agroforestry systems could be implemented on 585 to 1275 × 10 ha of technically suitable land and this system could store 12 to 228 Mg C/ha under the prevalent climatic and edaphic conditions (Fig. 5).

Forest management practices and C-sequestration

Forests accounted for about 80% of carbon exchange between terrestrial ecosystem and the atmosphere. Forest ecosystems are estimated to absorb up to 3 billion tonnes of carbon annually. Soil organic carbon levels in agricultural sites are getting depleted; therefore, forestry practice would not only improve soil quality but also increase the amount of carbon sequestered. In forestry system trees being perennial remain on the site for many years and

shed their litter on soil surface. Most of the carbon enters the ecosystem *via* photosynthesis in the leaves. More than half of the assimilated carbon eventually transport to soil *via* root growth, root exudates and litter decomposition.

Forest management activities include:

Carbon sequestration – through afforestation, reforestation and restoration of degraded lands, improved silvicultural techniques to increase growth rates and implementation of agroforestry practices on agricultural land.

Carbon conservation – through conservation of biomass and soil carbon in existing forests, improved harvesting practices such as reduced impact of logging, improved efficiency of wood processing, fire protection.

Carbon substitution – through increased conversion of forest biomass into durable wood products, increased use of bio-fuels such as introduction of bio-energy plantations and enhanced utilization of harvesting wastes.

SUMMARY

From the above discussion it can be concluded that the process of carbon sequestration is neither tough nor easy rather it includes the basic sustainable practices and exploitation of natural resources and mechanisms, but it depends upon how we execute it to achieve our goal. It requires knowledge, thorough understanding of methodology, proper channel to disseminate the technology, financial back up, administrative and legally bound effort. In the era of global warming and climate change, we need earnest and consistent effort to reduce CO₂ concentration from atmosphere and therefore for this soil carbon sequestration is indispensable.

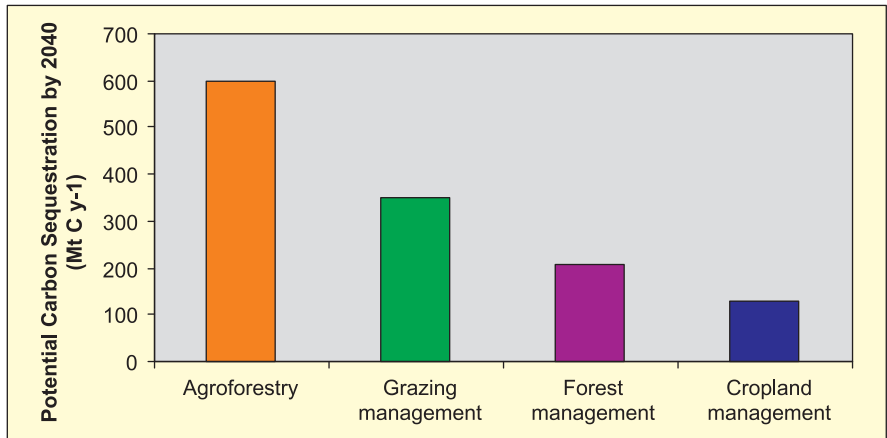


Fig. 5: Carbon sequestration potential of four land-use systems

¹Assistant Professor, ²Ph.D. Research Scholar, Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi 110012. ³Assistant Professor, RRS Terai Zone; Pundibari, Cooch Behar, West Bengal 736165; ^{4,5}Research Scholar, Department of Agronomy, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal 736165; Corresponding author's e mail: tarun.bckv@gmail.com