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Prof. S. Kannaiyan Memorial Oration - 2019

delivered during

11th NABS-National Conference

on

"Climate Change Driven Challenges on Indian Biodiversity: Innovative Solutions for Sustainable Development"

26-09-2019

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Convention-cum-Cultural Complex, Pondicherry University

Role of Carbon in Agriculture and Environment

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Soils are the third largest global reservoir of carbon (C) and the largest terrestrial ecosystem sink or source of atmospheric CO2 depending on land-use and management. Carbon is one of the most common elements in the universe and found virtually everywhere on earth: in the air, the oceans, soil, and rock. Among all the nutrients, carbon is the fourth most abundant element in the environment and it is a sixth element in Periodic Table and comes under group 14. It is fifteenth most abundant element in the earth's crust. This small six proton atomic element (atomic number: 6) "carbon" is the building block of life on earth. Carbon's importance arises from its crucial functions in structural stability as well as energy source for living creatures. Carbon's very long chains and rings are the backbones of most organic modules. In the living environment, carbon atoms form the structural and molecular backbone of the important molecules of life such as nucleic acids, proteins, carbohydrates and lipids etc. Carbon is a versatile element. It can exist in a very small two atom molecule such as carbon monoxide (CO) up to a molecule that contains thousands of atoms such as DNA and proteins. In the nonliving environment, we find carbon compounds in the atmosphere, carbonaceous rocks and fossil fuels such as coal, oil and gasoline etc.

Carbon compounds can exist as gases, liquids and solid forms. The atoms of carbon can bond together in different ways, termed allotropes of carbon. The best known are graphite, diamond and amorphous carbon. The physical properties of carbon vary widely with the allotropic form. For example, graphite one of the softest material while, diamond is the hardest material known. Graphite is opaque and black, while diamond is highly transparent. Graphite is a good electrical conductor while diamond has a low electrical conductivity.

Global carbon cycle

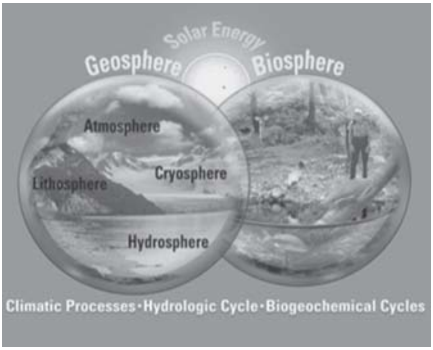
The carbon cycle is a fundamental part of life on earth and is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth. Carbon that is not tied up in rocks or deep in the oceans is constantly changing and moving. This process is called as carbon cycle. Movement of CO2 from the atmosphere into land via photosynthesis and root respiration, the subsequent formation of bicarbonate in the soil, and its storage in groundwater or precipitation as CACO3 in dry land soils are major processes in the global C cycle. Together, inorganic C as soil carbonate and bicarbonate in groundwater surpass soil organic C as the largest terrestrial pool of C.

Recent studies have found that the mobilization and deposition of agricultural soils can also significantly alter nutrients and carbon cycling. In eroding sites, the physical removal of SOC causes a depletion of the carbon pool, which may be partially compensated by the incoming fixed carbon. In addition considering the same depth, the exported SOC is replaced by more recalcitrant subsoil pools leading to complex feedbacks on vertical fluxes components (respiration and fixation). All these complex interactions still feed the dichotomous debate whether the erosion induces a net carbon source sink.

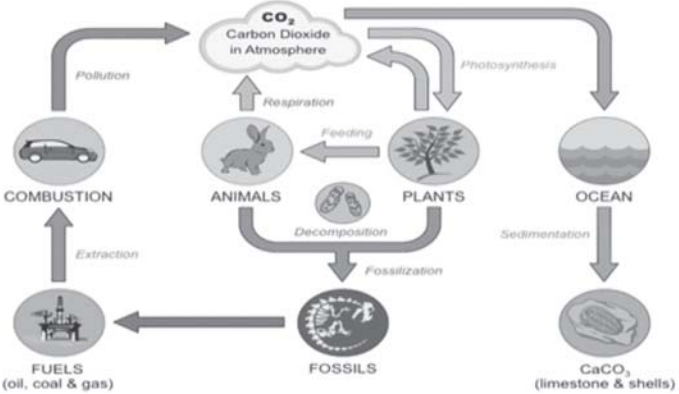
On earth, carbon compounds circulate through land, the atmosphere, oceans and all the organisms that live there. All the components comprise the global carbon cycle. The global carbon cycle can be subdivided in

1. Biosphere carbon cycle

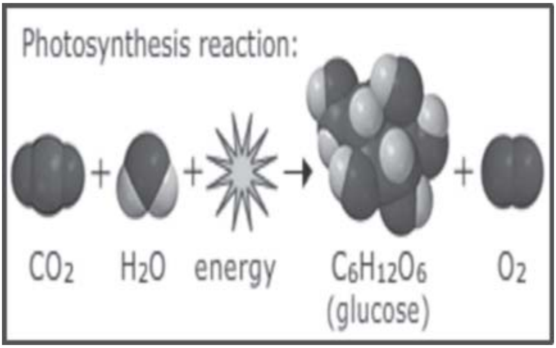
2. Geosphere carbon cycle.



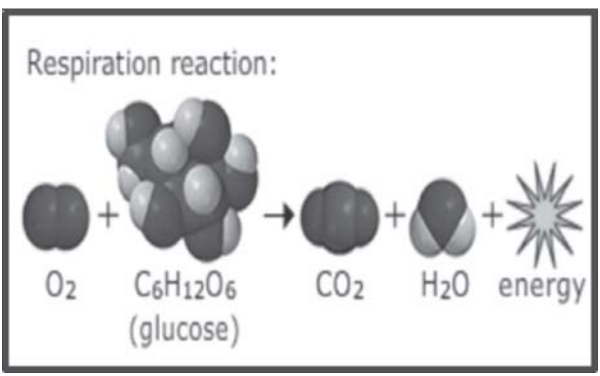
The amount of carbon stored in biomass depends on the balance of carbon input via photosynthesis and carbon output via respiration



Biosphere carbon cycle operates on time scales of seconds up to hundreds of years. The photosynthesis, respiration and biosynthesis are the key biosphere processes that convert carbon compounds into new forms. Biosphere organisms are from smallest microbes to largest trees, have a key role in converting carbon compounds into new forms. The amount of carbon stored in biomass depends on the balance of carbon input via photosynthesis and carbon output via respiration. Photosynthesis is the carbon cycle process that moves carbon atoms from the atmosphere into trees and all other plants.



Respiration is the key carbon cycle process that moves carbon atoms out of plants into the atmosphere, surrounding soil or water.



Biosynthesis is the key carbon cycle process that generates gains in biomass. Net primary production (NPP) is a measure of the amount of carbon stored mostly as biomass. There is no doubt that the above three processes are very important, crucial life processes in agriculture. Carbon in the form of CO2 and carbohydrate ar essential part of nucleic acids, proteins and lipids. The main source is carbon dioxide that is there in the atmosphere and the main entry of carbon into the plant system is through photosynthesis.

In geosphere carbon cycle operates at very long time scale of thousands to millions of years. Sedimentation, lithification, tectonics and volcanism are important geosphere processes that converts carbon compounds into new forms.

Agriculture's Role in the Carbon Cycle

Carbon is critical to soil function and productivity, and a main component of and contributor to healthy soil conditions. Soil management plays a critical role in whether the carbon remains in the soil or is released to the atmosphere. Agricultural practices can impact both the amount and the composition of soil organic carbon and hence also the soil's physical, biological, and chemical condition, the combination of things that defines soil health. Farm practices that affect carbon therefore impact agricultural productivity and resilience (the soil's ability to deal with weather extremes) and the carbon cycle itself.

Essential elements for plants

Carbon is one of the sixteen essential elements which are essential for plant growth. They can be divided into macro and micro nutrients.

Macro - (Non mineral Elements): required in relatively large amounts, Carbon (C), Hydrogen (H), Oxygen (O)

Macro - (Primary Nutrients): Nitrogen (N), Phosphorus (P), Potassium (K),

Macro - (Secondary Nutrients): Calcium (Ca), Magnesium (Mg), Sulfur (S),

Micronutrients : Iron (Fe), Copper (Cu), Zinc (Zn), Boron (B), Molybdenum (Mo), Manganese (Mn), Chlorine (Cl)

Very recently nickel has been added as seventeenth essential element for plants.

Soil health, soil organic matter (SOM) and soil carbon

Soil holds the largest portion of active carbon on earth. Carbon is critical to soil function and productivity and a main contributor to healthy soil conditions. Though the plants take carbon through atmosphere for its photosynthetic process, carbon in the soil is mostly essential for sustained soil health through microbial reactions and other processes that takes place in the soil. Majority of carbon enters the soil in the form of complex organic matter (plants and animals). Soil organic matter consists of decomposed plant and animal matter.

The SOM is composed mainly of carbon, hydrogen and oxygen, and has small amounts of other elements, such as nitrogen, phosphorous, sulfur, potassium, calcium and magnesium contained in organic residues. It is divided into 'living' and 'dead' components and can range from very recent inputs, such as stubble, to largely decayed materials that are thousands of years old. About 10% of below-ground SOM, such as roots, fauna and microorganisms, is 'living'.

The SOM exists as 4 distinct fractions which vary widely in size, turnover time and composition in the soil:

1. Dissolved organic matter
2. Particulate organic matter
3. Humus
4. Resistant organic matter.

Soil management plays an important role in whether the carbon remains in the soil or is released to the atmosphere. The agricultural practices can impact both the amount and the composition of soil organic carbon and hence also the soil's physical, biological, and chemical properties, the combination of these things that defines soil health.

The soil organic carbon (SOC) is the amount of carbon stored in the soil which is a component of SOM-plant and animal materials in the soil that are in various stages of decay.

Soil organic carbon and global carbon cycle

The amount of C in soil represents a substantial portion of the carbon found in terrestrial ecosystems of the planet. Total C in terrestrial ecosystems is approximately 3170 gigatonnes. Of this amount, nearly 80% (2500 GT) is found in soil. Soil carbon can be either organic (1550 GT) or inorganic carbon (950 GT). The latter consists of elemental carbon and carbonate materials such as calcite, dolomite, and gypsum. The amount of carbon found in living plants and animals is comparatively small relative to that found in soil (560 GT). The soil carbon pool is approximately 3.1 times larger than the atmospheric pool of 800 GT. Only the ocean has a larger carbon pool, at about 38,400 GT of C, mostly in inorganic forms.

Influence of SOC on Water-Holding Capacity and Porosity

Organic matter improves soil aggregate and structural stability which, together with porosity, are important for soil aeration and the infiltration of water into soil. While plant growth and surface mulches can help protect the soil surface, a stable, well-aggregated soil structure that resists surface sealing and continues to infiltrate water during intense rainfall events will decrease the potential for downstream flooding. Porosity determines the capacity of the soil to retain water and controls transmission of water through the soil. In addition to total porosity, the continuity and structure of the pore network are important to these functions and to the further function of filtering out contaminants. Finally, the water stored in soil serves as the source for 90 per cent of the world's agricultural production and represents about 65 per cent of global fresh water.

SOC and Biodiversity

Soil biodiversity reflects the mix of living organisms in the soil. These organisms interact with one another, as well as with plants and small animals, forming a web of biological activity. On the one hand, soil biodiversity contributes greatly to the formation of SOM from organic litter, thereby contributing to the enhancement of SOC content. On the other hand, the amount and quality of SOM (and consequently SOC) determines the number and activity of soil biota that interact with plant roots. Therefore, the soil microbial community structure is influenced largely by the quality and quantity of SOC and to a lesser extent by plant diversity.

Soil organic carbon and climate change

There is a growing body of evidence supporting the hypothesis that the earth's climate is rapidly changing in response to continued inputs of CO2 and other greenhouse gases (GHGs) to the atmosphere resulting from human activities (IPCC 2007). While a suite of GHGs exist (e.g., N2O, CH4), CO2 has the largest effect on global climate as a result of enormous increases from the preindustrial era to today. Atmospheric CO2 concentrations have risen from approximately 280 parts per million (ppm) prior to 1850, to 381.2 ppm in 2006 (WMO 2006), with a current annual increase of 0.88 ppm (3.5 GT C/yr) (IPCC 2007). Approximately two-thirds of the total increase in atmospheric CO2 is a result of the burning of fossil fuels, with the remainder coming from SOC loss due to land use change, such as the clearing of forests and the cultivation of land for food production.

While the carbon released to the atmosphere through deforestation includes carbon emitted from the decomposition of above ground plant biomass, carbon levels in the soil are also rapidly depleted from the decomposition of SOM. The decomposition of SOM is due to the activity of the microbial decomposer community in the absence of continual rates of carbon input from the growth of forest vegetation, as well as increased soil temperatures that result from warming of the ground once the forest canopy has been removed. Although this soil carbon loss has contributed to increased CO2 levels in the atmosphere, it also is an opportunity to store some of this carbon in soil from reforestation.

Soil organic carbon and Carbon sequestration

Soil organic carbon is the basis of soil fertility and releases nutrients for plant growth, promotes the structure, biological and physical health of soil and a buffer against harmful substances. Soil organic carbon is part of the natural carbon cycle and it accounts for less than 5% on average of the mass of upper soil layers and diminishes with depth. According to

CSIRO, in rain forests or good soils, soil organic carbon can be greater than 10% and in poorer or heavy exploited soils, levels are likely to be less than 1%.

Carbon sequestration (carbon farming) is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.

The soil carbon sink capacity is estimated at 10-60 mg/hm2. Principal strategies for soil organic carbon (SOC) sequestration involve: (i) restoration of degraded/desertified soils through conversion to perennial land use, and (ii) adoption of recommended management practices (RMPs) such as no-till farming, manuring, agroforestry, and use of biochar as a soil amendment.

The development of agriculture during the past centuries and particularly in last decades has entailed depletion of substantive soil carbon stocks. Agricultural soils are among the planet's largest reservoirs of carbon and hold potential for expanded carbon sequestration, and thus provide a prospective way of mitigating the increasing atmospheric concentration of CO_2.

At the same time, this process provides other important benefits for soil, crop and environment quality, prevention of erosion and desertification and for the enhancement of bio-diversity. Land degradation, does not only reduce crop yields but often reduces the carbon content of agro-ecosystems, and may reduce biodiversity.

Types of carbon sequestration

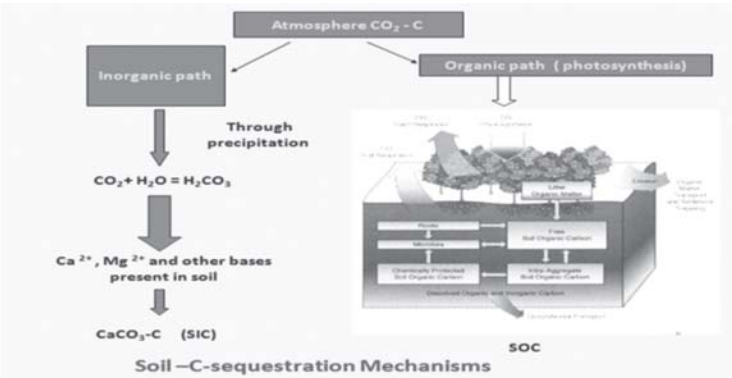
There are three main types of carbon sequestration:

- Carbon sequestration in terrestrial ecosystems - increasing the amount of carbon stored in vegetation and soils.

- Carbon Sequestration in the Oceans - enhancing the net uptake of carbon from the atmosphere by the oceans, through fertilization of phytoplankton with nutrients and injecting carbon dioxide to ocean depths greater than 1000 meters.

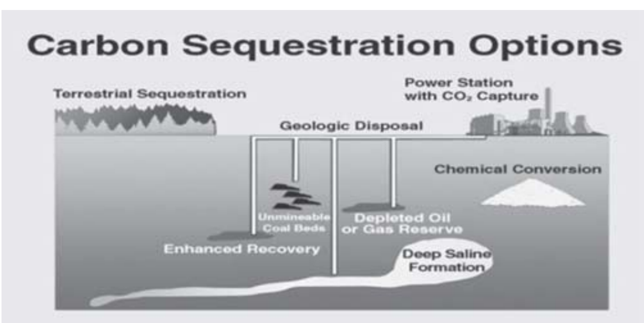
- The subsurface sequestration of carbon dioxide in underground geological repositories.

All of these options are commonly known as carbon "sinks". Increasing carbon storage in terrestrial ecosystems is currently the focus of most attention and is the easiest and most immediate option.



Mechanisms of soil carbon sequestration

- Pumping carbon into "carbon sinks"-an area that absorbs carbon
- Natural sinks-oceans, forests, soil, rocks, atmosphere
- Carbon can be pumped into empty oil reserves



Carbon is physically and chemically protected in soil. Physically-aggregates size classes - mean residence time is 20-250 years.

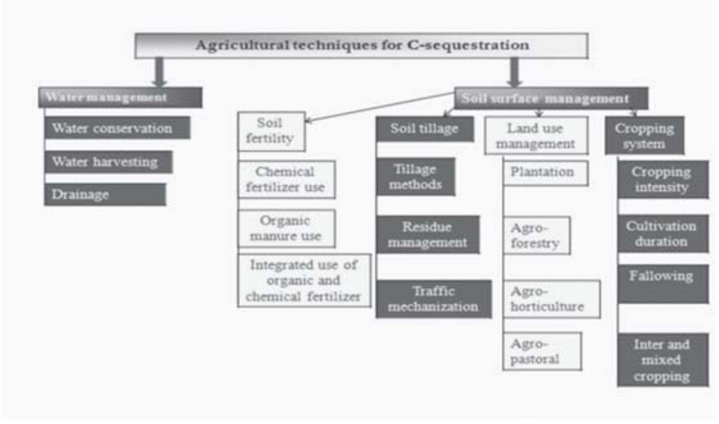
Chemically-clay-organo-mineral complexes - mean residence time is 250- 1500 years. Biological stable-recalcitrant.

Agricultural techniques for C sequestration

Low carbon agriculture refers to the method or practice of agriculture that is less a source and more a sink of carbon. A practice having low carbon and high carbon footprint is largely decided by the management practices adopted. However identification and adoption of best management practices.

Consequences of C loss in Soil

- Decline in productivity
- Reduction of soil biota
- Increase in soil erosion
- Reduction in aggregates stability
- Lowering water retention capacity of soil
- Adverse hydraulic properties
- Nutrients depletion
- Decrease in CEC
- Resilience to compaction



Strategies for enhancing SOC

- Controlling top soil erosion
- Conservation tillage (specially reduced and minimum tillage) and crop residue management, mulching, etc

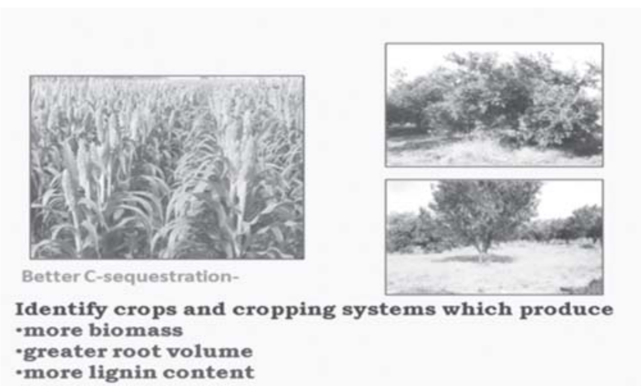
- Balanced and adequate fertilization and integrated nutrients use
- Inclusion of legume in cropping systems
- Green manuring and green leaf manuring
- Carbon sequestration through agro-forestry tree species and its recycling by leaf litter fall and pastures
- Use of soil amendments
- Regular use of manures

Potential of sugarcane

- C4 plant
- Absorb large quantity of CO2
- Minimizes entry of pollutants
- Fixes 1.4 billion ton of CO2
- Release 1.09 tone of O2 annually

One hectare area of sugarcane yields

- 8 to 10 tons of sugarcane trash,
- 4 to 5 tons of stubbles and adequate amount of root mass,
- 4 to 5 tons of press mud cake,
- 20 to 25 tons of baggasse
- 12,000 to 18,000 L of post bio-methanated spent wash



Identify crops and cropping systems that which produces more biomass, greater root volume, more lignin content, improved agriculture practices.

Potential of bamboo

Bamboo absorbs carbon dioxide and releases over 30 % more oxygen into the atmosphere compared to an equivalent mass of trees. This makes bamboo excellent for absorbing greenhouse gases and producing clean, fresh oxygen.

Social, economic and environmental benefits of soil C-sequestration

- Enhanced soil quality with the abundant increase in productivity and income.
- Enhances food, nutritional and livelihood security.
- Improve water storage.
- Reduced risks of soil, air and water pollution such as eutrophication.
- Increased soil biodiversity.
- Enhances physical, chemical and biological properties of soil.
- Reservoir of metabolizable energy for soil microbial and faunal activity.
- Effects in stabilizing enzyme activities.
- Value of source of plant nutrition through mineralization.
- Rehabilitates degraded lands
- Reduces risk for crop failure.

Michael Pilarski is a multi-disciplinary thinker, specializing in organic, sustainable agriculture, forestry, agro-forestry and permaculture. He is a farmer, tree-planter, author and educator. He has planted 80,000 trees so far. He has developed friends of the Trees Society. He has suggested a carbon sequestration proposal for the world based on reforestation, improved ecosystem management and increasing soil C levels in farm soils

There are four main themes in this proposal:

1. Reforestation/afforestation of 5 billion acres worldwide = 150 billion tons of carbon sequestration.

2. Earth repair and improved ecosystem management of existing forests and all other terrestrial ecosystems = 100 billion tons of carbon sequestration. This includes cities, forests, marshes, savannas, grasslands, steppes, and deserts. (this is a conservative estimate.)

3. Increasing the soil organic matter content by 1% on arable farmland worldwide = 43.86 billion tons of carbon sequestration (75.62 billions tons of soil organic matter which is 58% carbon). These figures are for the top one foot of the soil. Most farm soils in the world currently have between 1% and 3% organic matter levels.

4. Mobilizing the people and resources to accomplish these goals.

Concept of "Carbon Trading" and "Carbon Credit"

The impact of climate change on various spheres of human life has been clearly noticed. Scientific evidences clearly implicate the role of greenhouse gases (GHGs) in global warming. The role of GHGs in the climate change has led to international negotiations, resulting in recognition of C as a tradable commodity and the growth of the global C market.

Carbon credit is currency for trading carbon. Carbon credits are certificates issued to countries/organisation that reduce their emission of GHGs below baseline. Carbon credits or Certified Emissions Reductions (CER) are a "Certificate" just like a stock. A CER is given by the CDM Executive Board to projects in developing countries to certify they have reduced green house gas emissions by one ton of carbon dioxide per year.

The mechanisms of emission reductions to earn carbon credits are Clean Development Mechanism (CDM), Joint Implementation (JI) and Emissions Trade (ET).

Carbon Credit

One ton of CO2 or its equivalent greenhouse gas (GHG) which is an entitled certificate by UNFCCC (United Nations Framework Convention on Climate Change)

Carbon credit is a financial instrument that allows the holder, usually an energy company, to emit one ton of carbon dioxide. Credit are awarded to countries or groups that have reduced their greenhouse gases below their emission quota. The C credits can be legally traded in the international market at their current market price.

Examples of Carbon Credit

- Trees of the future, an environmentalist group that works to reduce megatons of greenhouse gases from the atmosphere, plants enough trees to reduce emissions by one ton and is awarded a credit.
- If Hesteel Group, a steel producer, has an emissions quota of 10 tons but is expected to produce 11 tons, it can purchase the carbon credit from the environmental group.
- The carbon credit system looks to reduce emissions by ensuring that all countries keep their overall carbon emissions in check.

Carbon footprint

Carbon footprint is the sum of all emissions of CO2 (carbon dioxide), which were induced by your activities in a given time frame. Usually a carbon footprint is calculated for the time period of a year.

Carbon economy in Indian agriculture

The carbon economy in Indian agriculture can be improved through two principal modes, by reducing the total emission and by increasing the C sink. Under these two modes the major areas with scope for improving the C economy are outlined below

Enteric fermentation

The emissions from agriculture sector are dominated by the emissions from enteric fermentation from livestock, that contributes about 63 % of the total emissions from the agriculture sector (INCCA, 2010). Methane is the second largest contributor with share of 14.3 % of total anthropogenic GHG emissions estimated in 2004 (IPCC, 2007). The ruminants are capable of subsisting on relatively low quality forages and crop residues. Low intake clubbed with low digestibility of these feed resources contributes substantially to limit their productivity with emission of sizable quantity of CH4 (Sejian et al., 2011).

Manure management

Management decisions about manure disposal and storage affect emissions of CH4 and N2O, that are formed during decomposing manures. Although the CH4 and N2O emissions from manure management are minor, manure itself is an important contributor to emissions because it is either applied on croplands as organic fertilizer or directly deposited by grazing animals in pastures. Biogas generation from the cattle dung reduces the net emission under the particular area, despite efforts are needed to make the biogas technology popular.

Rice cultivation

The rice fields are a major source of emission of GHGs as CH4 and N2O. Researchers have attempted to model and estimate GHG emissions from rice fields under various growing conditions. However, there are uncertainties in the estimation of GHGs from Indian rice fields because of diverse soil and climatic conditions and crop management practices. Emission of the CH4 from paddy cultivation in India was estimated at about 4 million tons/year (Gupta et al., 2009).

Soil C sequestration

Soil C sequestration refers to removal of CO2 from atmospheric pool and its storage as soil organic matter. The potential of soil C sequestration in India is estimated at 39 to 52 million tons C yr-1 (Lal, 2004), that includes restoration of degraded soils (7.2-9.8 million t C yr-1) and reduction in erosion-induced emission of C (4.3-7.2 million tons C yr-1) (Lal, 2004). Further, permanence of C sequestered in soil depends on the continuation of the recommended management practices.

Burning of crop residues in field

Indian agriculture produces about 500-550 million tons (Mt) of crop residues annually. However, a large portion of this, about

90-140 Mt annually is burnt on-farm primarily to clear the fields for sowing of the succeeding crop (NAAS, 2012). Farmers prefer this practice to dispose off the crop residues of rice, wheat, maize and sugarcane. Emissions of CO2 during the burning of crop residues are considered neutral, as it is re-absorbed during the next growing season. However, biomass burning is one of the significant sources of atmospheric aerosols and trace gas emissions, that has a major impact on human health. In India, field burning of crop residues account for 257.21 thousand Mg of CH4 and 6.67 thousand Mg of N2O emissions annually (Sharma et al., 2011).

De-carbonization of fuel and alternate energy sources

The crop residues are being considered as a possible renewable source of energy. The opportunities for mitigating GHGs in agriculture centre around three basic principles: (1) reducing emissions, (2) enhancing sink or removals and (3) avoiding or displacing emissions. The third option relates to displacing the use of fossil fuels or de-carbonization of fuel use in agriculture sector. Several options are available under this category, such as use of biofuels, synthesis of biofuels from crop residues, mixing of biofuels with conventional fuel sources, etc. Further, there are also trade-off issues, that need to be looked into in each before making clear cut recommendations for farmers' adoption.

Additional benefits of C economy

The C economy achieved through soil C sequestration offers numerous additional and indirect benefits having implications for increasing agricultural productivity. It is estimated that 24 to 40 million tons of additional food grains can be produced annually if SOC pool in soils of the developing countries can be enhanced @1 Mg/ha/year (Lal, 2006). The factor productivity of the agricultural inputs such as fertilizers is largely regulated by the SOC content. With time, there is a decline in crop response to fertilizers. This trend not only reduces the net benefit of farmers, but also compels them to use more fertilizers, thus more GHG emissions from fertilizer production and use.

Under Indian conditions, the possible strategies to realize a significant effect of soil C sequestration (by improving the SOC stock), can be as follows:

- To reduce water erosion and thus minimizing the loss of SOC.
- Optimum and balanced plant nutrition through integrated nutrient management (INM) methods, which should be soil, crop and region specific.
- Restrictions (either through legal prohibition or incentivization) on crop biomass and residue burning.
- Promotion of conservation agriculture and minimum tillage methods.
- Creation of model villages for C economy to demonstrate an array of activities including biogas use, vermicomposting, on-farm biomass generation, tank silt application in crop fields, legume intercropping, bund planting with green manuring plants etc.
- Maintaining a minimum SOC level by regular additions of organic inputs.

Conclusion

Carbon is a versatile and most important element both in Agriculture and environment. More carbon should to be in soil than in atmosphere. Hence, Soil carbon management is an important strategy for improving soil quality, increasing crop yields, and reducing soil loss. Capturing carbon in the soil helps to improve soil health and benefiting agricultural production. Also stabilize the global carbon cycle, reducing CO2 emission into atmosphere and thereby check the global warming.

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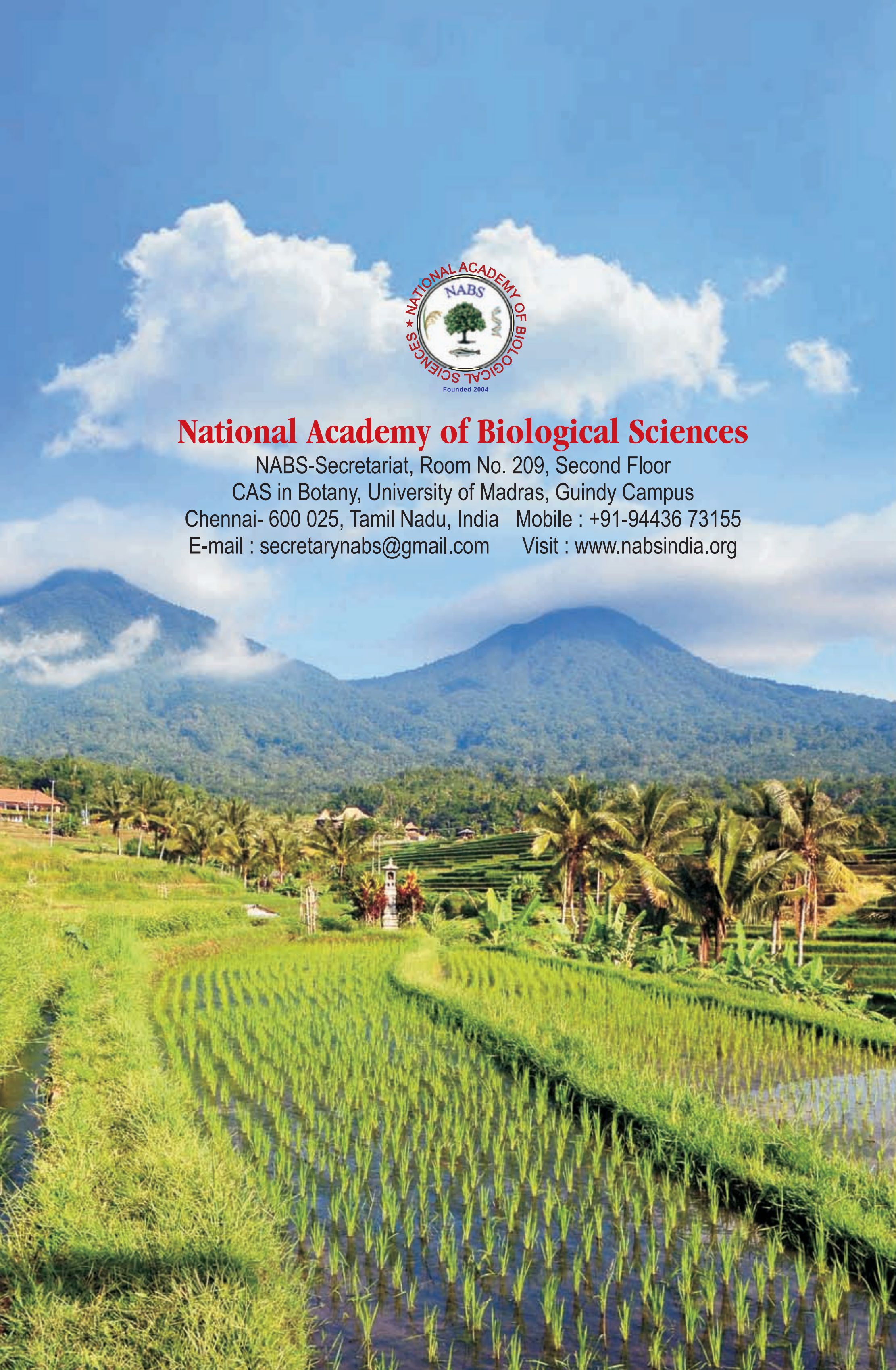

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