International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Prospective Scenario towards Carbon Dynamics of Indian Farming and Forestry Practices

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Received 12 July 2018, Accepted 15 Sept 2018, Available online 18 Sept 2018, **Vol.8, No.5 (Sept/Oct 2018)**

Abstract

India has been bright to harvest enough to feed its 1.25 + billion, as well as export farm and forest-based products to other countries. But the challenge to feed a projected population of 1.6 billion in 2050 and provide them with nutrition security under climate change scenes, is arduous because of the endlessly degrading natural resource base and shrinking of virtuous lands for forests and agricultural crops. It has been projected that to meet the demands of that vast population, there is an inevitable need of multifold enhancements in land productivity, water productivity and labor productivity as well. The current era of Anthropocene has been endorsed by both climatic and non–climatic factors, which will certainly increase the risk of food and water security across the globe. Among all, carbon (C) sequestration is one such important strategies that could mitigate the effect of above complex elements to a fair extent by transferring atmospheric carbon into the long- live natural pools such as soils, forests and perennial green biomass. The closing aspire of this write-up is to offer a fundamental perception on carbon dynamics and its integrated management on agricultural farms and forests along with predominant prospects to devise a cohesive approach for better perception and tackling of carbon-based managerial issues. Some valued food for thought is made part of this manuscript to realize active role as well as importance of land use and water conservation facets with futuristic R&D.

Keywords: *Carbon dynamics, low carbon concepts, farms and forests, agro-forestry, climate change, land use.*

1. Introduction

Agriculture's direct dependence on the natural resource base has always been a defining characteristic of this sector, because the production relies directly on soil, water, and a variety of natural and biological processes. It also adequately depends upon climate and its relevant aspects in regards to global carbon cycle. Today, more than ever before, we realize not only the significance that climate has for agriculture, but also the huge significance that agriculture has for the climate. The growing consensus on the need for a climate-smart agriculture emerged largely out of global awareness of farming sector's negative impacts, mainly its ecological footprint. It also grew out of the recognition that conventional forms of agricultural production are often unsustainable and thus deplete or "mine" the natural resources on which production relies over time. Farming is considered the world's leading source of methane and nitrous oxide emissions, a substantial source of carbon emissions, and the principal driver behind deforestation worldwide. Some 30 percent of global greenhouse gas emissions (GHGs) are attributable to farming and deforestation activities driven by enlargement of crop & livestock production for food, fiber and fuel. Looking upon these situations, majority of farms and forests remain at the heart of the transition towards low-carbon economies during current era of climate change.

As far as forests are considered, about one third of world's land area is covered by them being home to 80% global biodiversity and thus an effective means to reduce carbon dioxide (CO_2) emissions to enhance overall carbon sinks. It is truer for tropical locations like India, where each and every kind of forest-based involvement (agro-forestry, social & community forests, agro-horti-silvopastoral activities etc.) have equally vital facet for people & society via courses like deforestation, frequently releasing large amounts of carbon. Global efforts through Reducing Emissions from Deforestation and Degradation (REDD+), Kyoto-based Clean Development Mechanism (CDM) and voluntary carbon markets have proved ample options & solutions to release sureness on balanced forest activities (protection, reforestation, afforestation, management).

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DOI: https://doi.org/10.14741/ijcet/v.8.5.5

Forests & farms both have a key role to play in mitigation & adaptations towards carbon-based issues, because they exhibit dual function as 'sink' and 'source' of carbon emissions. Additionally, the produces/ products from these sectors have towering capabilities to displace more fossil fuel intense goods/harvest. Forest & farm management practices that can increase carbon sequestration and storage and reduce emissions include modification of rotation length; avoiding losses from pests, disease, fire and extreme weather; managing the soil carbon pool; and maintaining biodiversity. One-third of households worldwide (about 2.4 billion people) use wood as their main fuel for cooking and for boiling drinking water. About three-quarters of the 2.4 billion tons of annual global CO_2 emissions from wood fuel come from the use of wood fuel for cooking (R. K. Dixon *et al*., 1994). It clearly justifies the fact that wood energy & wood products have plentiful standing to take care of carbon issues, as only wood energy accounts for 7 % of global carbon emissions (R. Miner and C. Gaudreault, 2016).

It is the 'global carbon cycle' that describes the transfer of carbon in the earth's atmosphere, vegetation, soils, and oceans. The two prime anthropogenic processes responsible for release of CO_2 into the atmosphere are the burning of fossil fuels (coal, oil, and natural gas) and land use change. Mechanisms for carbon enhancement in such systems (agriculture or forest based) could be sizably boosted, once sustainable land management (SLM) concept is given its due importance. A proper integration of SLM could effectually delivers carbon benefits in three important ways; (i) by carbon conservation, in which large volumes of carbon stored in natural forests, grasslands, and wetlands remain stored as carbon stocks, (ii) By carbon sequestration, in which the growth of agricultural and natural biomass actively removes carbon from the atmosphere and stores it in soil and biomass, and (iii) By reducing the emissions of GHGs that emanate from agricultural production and land-use changes where carbon stocks may become carbon sources when farming production expands into natural ecosystems. Agriculture and forest both have profuse effects on earth's soils and the global carbon cycle. Land use concepts are age old notions. Agricultural land-use and land-cover change date back to about 12000 years ago when hunter-gatherers in the Fertile Crescent region of the eastern Mediterranean began using agricultural practices to manage soils. Since then, agriculture has spread across the globe and is now the dominant global land use with about 40% of the ice-free land area covered by croplands and grasslands (K. Lorenz and R. Lal, 2018).

Looking into above sphere of carbon-based problem, the most sensitive & important necessity remains a smart balancing among agriculture, forest, climate, and living populations (human, animals) on the globe. Certainly, there remains limits to which overall environment can adjust changes in these prime sectors. We don't know where the limit or limits are. There may be instances when only a small change can have a big impact and vice versa. The central theme of present article is to offer a thought-provoking discussion to reflect a fundamental basics of carbon-based issues on agricultural and forest lands along with a curtain raising on brief exertions performed in past and present to define and establish the role of farms and forests. Some of the quantified relevant paraphernalia is incorporated along with accessible technological options and thus paving a path towards futuristic targets on management and mitigation of climate change impacts on agricultural and forest lands and thus marching ahead with a need based, region specific and tailor-made R&D approach.

2. Carbon Fundamentals & Challenges

Forests and agricultural farms play an important role in controlling carbon dynamics and thus mitigating and adapting to climate change, hence they remain at the heart of emerging issues surrounding the climate. Owing to Global warming the planet's average temperature is rising due to an increased GHGs, especially CO_2 generated by human activity. At this crucial juncture, forests have ample abilities to store atmospheric CO_2 in wood (thanks to photosynthesis), as well as in the soil. By capturing nearly 20% of the world's carbon emissions every year, forests often act effectively as carbon sinks. However, under prevailing adverse climatic scenarios, majority of forests are being hit increasingly hard by adverse climate, with potential repercussions for their levels of production & economic viability. To mitigate effects of climate change, farm lands and forests play a central role at a number of levels. Using photosynthesis, their vegetative elements capture CO_2 from atmosphere and sequester it in the form of carbon in living biomass and later in dead biomass, leaf bedding & soils, acting as an effective "carbon pump" which makes the carbon pool a huge entity with diverse domain. Hence, the adverse effects of climate change can very easily gets combed by swelling area of woodland, planting more trees, or by optimizing existing forest management, producing high-quality wood for industry. The wood products that come from forests, sequester carbon throughout their use life and prolongs the storage of that carbon.

When we look into working physics of Carbon sequestration in farms and forests, it is often evident that carbon usually remains locked up in the chemical components of trees, litter, soil, and wood products. Physical & economic valuations have differed in their focus on these, as some times it remains concentrated on trees themselves and other times on soil or wood products (C. Price and R. Willis, 2011). The rate of buildup of carbon in trees has long been a subject of physical study, modelling and economic analysis (R. Olschewski and P. C. Benitez, 2010), evidencing climate change and land use change impacts. Forests cover across vast regions of the globe serves as a first line of defense against the worst effects of climate change, but only if we keep them healthy and resilient. Wood volume and biomass levels happens to be another important indicator to quantify the true potential of forests to sequester carbon. Because living forests trap and hold large amounts of carbon in their woody biomass they have been often identified as potentially important regulators of the global and local climate. Conversely, forests also may be a source of emissions when forests are burned or when wood from trees and other organic matter decomposes, releasing carbon dioxide back into the atmosphere. When it comes to carbon forestry, there's no substitute for a rigorous breakdown of biomass stocks and directly measured growth rates in given area.

2.1 Global Carbon Situation

The biking of carbon in farming and forest ecosystems is still to be well understood, as there remains a constant flux and exchange between a forest ecosystem and atmosphere. The Earth's atmosphere encompasses about 0.04% CO_2, which is removed by forest ecosystems through photosynthesis; where green leaves utilize energy captured from sunlight to chemically combine water & CO_2 producing sugars and oxygen. The sugars are used to produce carbon-based cellulose, the primary structural component of all plant cells. As a result, the carbon is tied up in all of a tree's tissues (roots/stems/leaves). Carbon is given off from farming and forest ecosystems through respiration in which oxygen & sugars are converted to CO_2 and water i.e. the reverse of photosynthesis. Energy is produced which is needed for a tree's metabolic activity, hence as a plant or tree grows, it will continue to tie up more & more carbon. In fact, trees will continue to store more carbon than they give off until maturity or old age at which time a homeostasis is usually arrived.

After deep oceans and coal/oil sector, it is plants and soil domains which offers tremendous opportunities for understanding and regulating the carbon pools for the benefit of mankind as well as environment. If we look upon the proportionate quantified distributions of carbon in soils and plants, it has wide variations across different regions of the world. Fig. 1 illustrates an elementary breakup of global carbon picture depicting its spatial distribution across the universe. Two major actors that deals carbon (soils & vegetation) have their well-established & budding roles as evident from a historic comparison (Table 1) where about 20 % of world carbon was found to get dealt by vegetation and remaining 80 % by soils/lands. A region wise spatial distribution for such variabilities is provided in the said table, which is self-explanatory to establish that out of total carbon stocks croplands and grasslands had been front-runner tackling more than 95 % carbon in soils. On the other side the soils of forest dominated regions dealt 50 to 80 % of their respective gross carbon stocks.

Erosion is another major land degradation process that emits soil carbon. Because soil organic matter is concentrated on soil surface, accelerated soil erosion leads to progressive depletion of soil carbon. Estimates of erosion-induced carbon emissions across different regions of world are reflected in Table 2, showing magnitudes and trends of variability for soil carbon displaced by erosion across various global regions. Asian regions remain most susceptive & sensitive, inviting greater attentions on carbon management.

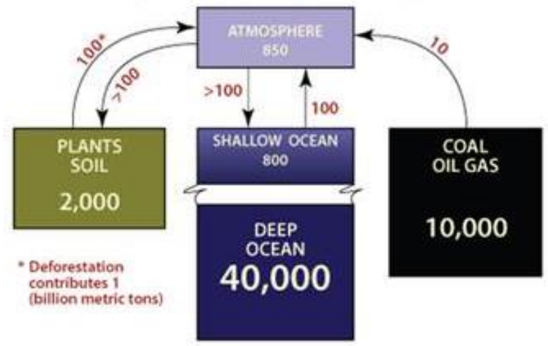

Fig. 1 Global carbon pool showing stocks and flows of carbon in billion metric tons/year

Table 1 Notable global carbon stocks distribution in vegetation & upper most 1-meter soils of world during 2000

Biomass Systems	Area	TCS	PCB % of total	
	Million Km^2	Gt C	Vegetation	Soils
Tropical forests	17.6	428	49.5	50.5
Temperate forests	10.4	159	37.1	62.9
Boreal forests	13.7	559	15.7	84.3
Tropical savannas	22.5	330	20.0	80.0
Temperate grasslands	12.5	304	3.0	97.0
Deserts	45.5	199	4.0	96.0
Tundra	9.5	127	4.7	95.3
Wetlands	3.5	240	6.3	93.8
Croplands	16.0	131	2.3	97.7
Total	151.2	2477	100	100

Source: John G. Watson et al. (2000)
PCB=Proportionate carbon stocks; TCS=Total carbon stocks

According to the 2017 Global Carbon Budget report India has been quietly emerging as climate performer cutting down on its emissions, they will rise only by 2 percent to 2.5 giga tons compared to 6.7percent in 2016. Measured per person, India's emissions are still very low being only 1.8 tons of CO_2 per capita; much lower than the world average of 4.2 tons. But those emissions have been growing steadily, with an average growth rate over the past decade of 6%. In spite of above facts, India use to be world's 4th largest emitter of CO_2. It is utmost imperative to understand what remains the influences of farms and forests to govern these emissions in future, when actors like climate, land use changes, population, socio-economic developments, are playing their active roles in adverse manners.

Table 2 Estimates of erosion-induced carbon emissions across different regions of world

Region	GE (Gt/year)	SCDE (Gt C/year)	EDSC in (Gt C/year)
Africa	38.9	0.8 - 1.2	0.16 - 0.24
Asia	74.0	1.5 - 2.2	0.30 - 0.44
South America	39.4	0.8 - 1.2	0.16 - 0.24
North America	28.1	0.6 - 0.8	0.12 - 0.16
Europe	13.1	0.2 - 0.4	0.04 - 0.08
Oceania	7.6	0.1 - 0.2	0.02 - 0.04
Total	201.1	4.0- 6.0	0.80 - 1.70

Source : R. Lal (2003)
GE = Gross erosion; SCDE = soil carbon displaced by erosion @ 2-3% of sediment;
EDSC= Emission @20% of displaced soil carbon

2.2 Essentials of Carbon Capture & Sequestration

Carbon capture and its sequestration (CCS) is gaining more importance under prevailing settings of farms, forests, climate, human and overall society. It used to be a low carbon working technology which captures CO_2 from the burning of coal & gas for power generation, and from the manufacturing of steel, cement and other industrial facilities, and transports it by either pipeline or ship, for safe and permanent underground storage, and thus preventing it from entering the atmosphere and contributing to anthropogenic climate change.

2.2.1 Fundamentals & Prevailing Situation

Basically, it involves a process for carbon capture and long-term storage of atmospheric CO_2 or other forms of carbon to mitigate or defer global warming. Before realizing the constituents of CCS, one must visualize some of the fundamental properties of CO_2 which remains the key entity of this innovative process. Typically (Fig. 2) the CO_2 use to be a colorless and, at low concentrations, odorless having molecular mass as of 44 g/mol. At standard temperature and pressure, its density remains around 1.8 kg/m^3, being 1.5 times that of air. Because it is heavier than air, it has a propensity to sink, at least in the absence of external convective mixing (breezes & winds). This makes CO_2 a safety hazard for asphyxiation. At 1 atmosphere (1.013 bar) CO_2 becomes a solid below 194.7K. Special interest for CCS is the supercritical region above this critical temperature, where the CO_2 is referred to as in the fluid (f) phase. In this fluid phase CO_2 may be pumped most easily through pipelines, because there is no liquid-vapor coexistence. A critical temperature near ambient conditions also implies that one can compress CO2 gas to a dense fluid without going through a phase transition consuming less energy.

When we look into technological architecture of CCS, there remains bellow given 3 fundamental stages in it,

- 'CO_2 capture' via industrial processes, removing CO_2 in high-purity, concentrated streams by adopting methods like (i) pre-combustion carbon capture, where fuel is gasified (rather than combusted) to produce a synthesis gas, or syngas, consisting mainly of carbon monoxide (CO) and hydrogen (H2) and later a subsequent shift reaction converts the CO to CO_2, and then a physical solvent typically separates CO_2 from H_2, (ii) post-combustion carbon capture, which typically uses chemical solvents to separate CO_2 out of flue gas from fossil fuel combustion, and (iii) oxyfuel carbon capture, which requires fossil fuel combustion in pure oxygen (rather than air) so that exhaust gas is CO_2-rich, which facilitates capture.
- 'CO_2 transportation' for transporting captured CO_2 from its source to a storage site via pipelines.
- 'CO_2 Storage' the final stage of any CCS plan, where CO_2 could be injected into geological formations (deep underground like deep saline creations). CO_2 storage skills for measurement, monitoring, verification, accounting, and risk assessment can substantially minimize/mitigate the potential of stored CO_2 posing risks to humans or environment. As a 2nd option, the coal beds that are too deep or too thin could be economically harnessed for ample CO_2 storage.

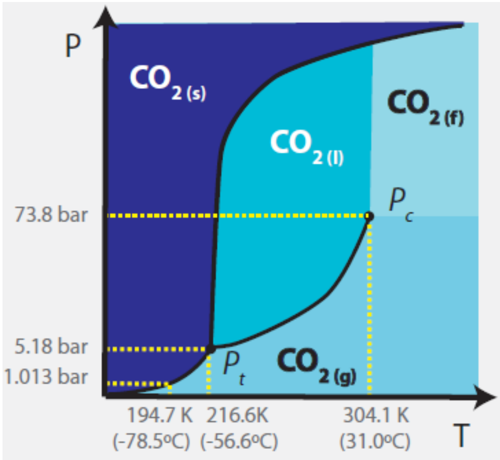

Fig. 2 Customary fluxes in CO_2 properties

Most of the world's soil carbon is stored at northern latitudes, with North America, Northern Europe and Russia accounting for more than half of the world's soil organic carbon stocks on croplands. In contrast, large areas of croplands in India, across the Sahel, northern China, and Australia have cropland soils that are low in carbon. Although the capacity to increase soil carbon depends to a large degree on the types of soils and the environment, all of the major agricultural countries in the world have shown a significant CCS potential. Whereas the United States has the largest area of croplands and consequently the largest sequestration potential, other major agricultural countries with large areas of cropland such as India, China, and Russia too can make substantial contributions for mitigating climate change through soil carbon sequestration.

3. Role of Farms and Forests towards Carbon

3.1 How they Tackle Carbon

Forests and agricultural farms play an important role in controlling carbon dynamics and thus mitigating and adapting to climate change, hence they remain at the heart of emerging issues surrounding the climate. Researchers (Lal, 2011) have well established the facts that there exists a tremendous scope for improvements in crop yields per tons of carbon in the root zone. Potential increases for such yields for crops like maize, wheat, soybean, cowpea, rice and millet are reported in the range of 200-400, 20-70, 20-30, 5-10, 10-50, and 50-60 Kg/ha respectively. By capturing nearly 20% of the world's carbon emissions every year, forests often act effectively as carbon sinks. However, under prevailing adverse climatic scenarios, majority of forests are being hit increasingly hard by climate change, with potential repercussions for their levels of production and the economic viability. Farms and forests tackle the carbon in a diverse way by striking carbon sinks, active links with climate, and basic inputs (water & energy).

3.1.1 By Acting as Carbon Sink

Any carbon sink could be considered as a natural or artificial reservoir that accumulates and stores some carbon-containing chemical compound for an indefinite period. Process by which carbon sinks remove CO_2 from atmosphere is termed as carbon sequestration. Public awareness of the significance of CO_2 sinks has grown since passage of the Kyoto Protocol, which promotes their use as a form of carbon offset. Farms and forests remain one of the biggest carbon stores, acting as CO_2 sinks. In some part of the globe, like in Canada as much as 80% of total carbon is stored in forest soils as dead organic matter. South American tropical forests, revealed the fact that on an average these lands absorb about 18% of all CO_2 added by fossil fuels. Based on various studies (Miner and Gaudreault, 2016) it has been estimated that Asian forests absorb about 5 tons of CO_2/ha/year. Carbon sequestered & stored in trees/forests is finally emitted back to atmosphere after trees are harvested or lost to natural mortality or disturbances such as pest outbreaks and fires. After harvesting, carbon is stored in harvested wood products throughout the lifetime of the product but is eventually lost to decay. Findings have well revealed interesting facts that global cooling effect of carbon sequestration by forests is partially counterbalanced and reforestation can sizably decrease the reflection of sunlight (albedo).

3.1.2 By Having Dynamic Links with Climate

Ecologists have long been interested in carbon, in particular on agricultural and forested landscapes. This interest stems from several reasons, like that the humans/plants/animals on earth are made primarily of carbon having nearly 50% of their dry weight as carbon. There exists plethora of scope to learn much about prevailing farm & forest-based ecosystems via regional synthesis of carbon & energy budgets to evaluate productivity, food chains, and nutrient cycling. It altogether links farming and forestry-based activities with predominant climatic situations. By now, we all well realized that climate change is real and it is intensively and unpredictably happening now. Humans are causing it and only they can stop it using science-based principles and interventions. In accordance to information released from WHRC (2017) a large-scale tree planting effort in India, China and South Korea have removed more than 12 billion metric tons of CO_2 from the atmosphere during past 20 years. How can other countries or regions can replicate this success? Their analysis has amply illustrated answers to this basic question where affected regions can protect, expand and improve the carbon management on their farms and forests. By stopping deforestation and allowing young secondary forests to grow back, the world's cumulative "forest sink" could grow by more than 100 billion metric tons of carbon by 2100, being about 10 times of current annual global fossil fuel emissions rate.

3.1.3 By Regulating Water and Energy Inputs

Universal endeavors through REDD+, CDM and willful carbon markets have exhibited adequate endeavors and answers to discharge certainty towards altering workouts of forests (safeguarding, reforestation, afforestation, administration) to preserve natural resources like water and energy. Agriculture accounts for more than two-thirds of the world's freshwater use, and it is contributing sizably to deforestation. A 70% expansion to feed the exploited population of world, cannot follow the practices of the past and still being sustainable. By 2050, the Earth will need to feed 9 billion people with the same amount of land and water used today. In practice, this means agricultural production must increase by 70 percent. The answer lies in pursuing a landscape approach – recognizing that agriculture, water, forests, and food security are all well connected. It can help to maximize productivity, improved livelihoods, and reduced negative ecological impacts, if they are considered in an integral way.

3.1.4 By Offering Innovative Interventions

Farms and forests offer enormous potential for innovative R&D inferences to tackle carbon. There exists plethora of revolutionary options based upon traditional as well as advanced knowledge systems on such lands, with which carbon related issues might be effectually regulated and potential benefits could be harnessed thereupon. Fuller description of all such intrusions is out of scope here, moreover conservation agriculture, precision agriculture, agro-forestry, region specific tailoring of land use configurations etc. are some of the dominate areas where carbon related questions could be tackled preciously and economically (S. Puri and P. K. R. Nair, 2004). One of the most updated evaluation speaks that clearing of natural vegetation to make room for cultivating crops has released up to one-third of the soil organic carbon stock from the top 1meter of soil, and the effects on the soil inorganic carbon stock still continue to be unnoticed. GHGs produced in anaerobic environments under agricultural practices, such as the sediments of wetlands, peatlands, and rice, livestock production has emerged as a big concern for present society. Accordingly, appropriate innovative interventions on farms and forest are true need of hour.

3.2 Carbon Dynamics across Forests/Farms

Carbon exists both in natural & artificial sinks, where natural sinks are typically bigger than artificial sinks. It includes absorption of CO_2 by oceans via physico-chemical & biological processes and photosynthesis by terrestrial plants. If we look into the main artificial sinks, 2 broad categories of carbon sources remain, (i) combustion of fossil fuels (coal, natural gas, oil) by humans for energy/ transportation, and (ii) farmland (by animal respiration). Oceans remains most active CO2 sinks, and represent the largest active carbon sink on earth, absorbing more than a quarter of the CO_2 that humans put into the air. Afterward, it is the soils that represent a short to long-term carbon storage medium, and contains more carbon than all terrestrial vegetation and the atmosphere. Current agricultural practices lead to carbon loss from soils. That is why it is suggested that improved/effective farming practices could return soils back as a carbon sink.

Forests plays an extremely important role towards dynamics of carbon, maybe it is over the ground, under the ground or even above the ground. At present forests covers just over 4 billion hectares or roughly 31% of the earth's surface and sequester (absorb or remove from the atmosphere) & store large quantities of carbon. The trend of forest depletion in past 25 years is of utter distressing giving consistent sharp declines (FAO, 2006). Forest ecosystems are estimated to store about 650 billion tons of carbon (44% in biomass, 11% in necromass and 45% in soils) and absorb 8.5 billion tons of CO2 per year from atmosphere. The UN's Intergovernmental Panel on Climate Change, using 1980s and 1990s-era forest surveys and satellite data, estimated that deforestation was responsible for around 17% of total annual global GHG emissions. (IPCC, 2007)

In accordance to most recent global scenario; up to 357 Pg (1 Pg = 1 Gt = 10g) C pre-1850 and 168 Pg C post-1850 may have been released by agricultural land-use changes. If we would have considered depth more than 1 meter these estimates could have been further high. If we consider only crop and pastures, one of the most recent guesstimates on LULCC emissions from 1850 to 2015 projects it as 98.4 and 16.3 Pg C respectively. This altogether invites bigger attentions towards climate change adaptation and mitigation by sustainably intensifying production amidst the increasing challenge of satisfying the demands for food, feed, fiber, and fuel of a growing, more affluent, and more animal products consuming population (K. Lorenz and R. Lal, 2014). Most recent effort namely '4 per Thousand Initiative (4p1000)' as proposed in December 2015 at COP21 in Paris, advocates to augment the soil C stock on a large portion of the world's managed soils by an average annual increase of 0.4% in 0–40 cm depth (Lorenz and Lal, 2018).

4. Low Carbon Opportunities

There occur enormous R&D efforts to release vast technological & policy-based corridor for growing nations like India, where the so-called threat of 'carbon' could be well transformed into an opportunity (G C. V. Kooten, 2015). A brief description to this regard is offered below by using the outcomes of many outcomes by sailing across vast literature for conceiving this though provoking writeup.

4.1 Technological Options

India use to be world's 2nd most populous country with a rapidly growing economy and increasing emissions having looming threat of anthropogenic climate change in coming decades, where CCS based interventions could play a pivotal role to overcome the problems. Looking into prevailing demands many technological decisions/efforts are being undertaken to set right targets with right pace of desired actions. Most Indian R&D activities related to CCS occur under Department of science & technology, where a national program on carbon sequestration research is commissioned in 2007. Four vital thrust areas of research are (i) CO_2 sequestration through micro algae bio-fixation techniques; (ii) carbon capture process development; (iii) policy development studies; and (iv) network terrestrial agro-forestry sequestration modeling.

Salient researchable issues and later some of the preliminary efforts towards them are gaining ample momentum, which includes potential areas at micro scales too. Some of them are,

- Advanced pre-& post combustion technologies (membrane reforming etc.)
- Feasibility studies of CO_2 storage in India
- Bio-sequestration, i.e. carbon management in forests
- A 'biomimetic' approach, i.e. identification of a biological process to utilize CO_2
- Potential of enhanced recovery of oil & methane
- Micro algae growth for the extraction of biodiesel
- Harnessing potential utilities of bamboo plantains
- Conservation & precession agriculture
- Smarter irrigation tools and techniques
- Enhancement of NRM and water use productivities

4.1.1 Managing Soil Carbon

Soil carbon has vast importance because of its role in the global carbon cycle and the part it plays in the mitigation of atmosphere levels of GHGs, with special reference to CO_2. Globally, soil organic carbon at the 0 to 30 cm surface level comprises around 66.5 Gt CO2e (E. G. Jobbagy and R. B. Jackson, 2000), which use to be the largest terrestrial carbon pool being 2 to 3 times more carbon than what is held in the atmosphere (E. A. Davidson *et al*. 2000). Ample Interest in the contribution of such soil carbon pool to mitigation strategies has been growing, with a well-established indication that even a 5 % increase in the size of soil organic carbon pool with modified land management techniques could result in up to a 16 % reduction in the amount of atmospheric carbon (K. Paustian *et al*., 2000). CCS could be an excellent imperative option to reduce/regulate the emission of CO_2. Among the other known sources that enhance CCS, the role of soil in capturing and storing carbon has not been adequately shielded. As per another estimate, the forests were containing 39 percent of all carbon stored in soils (Eliasch, 2008), which remained vastly varied among regions and forest types. These variations have been further moved apart in present days conditions. Since, forest management practices are intricately related to management of the soil carbon pool, preventing deforestation and forest degradation always has an important role in maintaining soil carbon stocks, which in turn strengthen the functional relationship between biodiversity and carbon sequestration (S. J. George *et al*., 2012). Table 1 illustrates the prevailing situation in regards to carbon pools for major soil orders of India.

4.1.2 Agroforestry based Interventions

Agroforestry is an innovative practice of introducing trees in farming to play a significant role for enhancing land productivity and improving livelihoods. For regions like India, it has always offered a vital scope to deal with carbon management. Carbon sequestration through agroforestry offers several distinct advantages like, improved soil fertility, controls & prevention of soil erosion/water logging, and acidification/ eutrophication of streams & rivers, increase in local biodiversity, decrease in pressure on natural forests for fuel and thus provides fodder for livestock. It also has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. The effectiveness of agroforestry systems in storing carbon often depends both on environmental as well as socio-economic factors. In humid tropics, agroforestry systems are found to offer carbon sequester over 70 g/ha in the top 20 cm of the soil. The carbon storage capacity in agroforestry varies across species and geography. Further, the amount of carbon in any agroforestry system depends on the structure and function of different components within the systems put into practice (R. Newaj and S. K. Dhyani, 2008). According to the IPCC (2007) even globally, the Agroforestry systems offer important opportunities of creating synergies between both adaptation and mitigation actions with a technical mitigation potential of 1.1-2.2 PgC in terrestrial ecosystems over the next 50 years. Additionally, 630 Mha of unproductive croplands and grasslands could be converted to agroforestry representing a carbon sequestration potential of 586000 MgC/yr by 2040 (S. Jose, 2009).

4.2 Policy based Enhancements

Policies in regards to farms and forests remain the key bottle necks for effective implementation of technologies and approaches via broader and deeper replications of success stories and proven interventions that have been recognized across the globe. More recently ample importance is being given to this front, where endeavor towards climate change mitigation via carbon of farms and forest are getting well established.

In India, most recently the newer national policies towards forests and agro forestry are re-aligned with scientific gestures, where ample room is given for managing carbon stocks via conserved and enhanced activities like (i) Planting and/or regenerating trees on barren/non-forested land, degraded forests, agricultural and urban landscapes including afforestation, reforestation, forestation, forest rehabilitation, forest restoration, agroforestry, urban forestry and enrichment planting; (ii) Conserving existing farms and forests and avoiding their degradation or conversion to alternative land use by avoiding deforestation, REDD, and conservation of forest carbon stocks; (iii) Improved or sustainable forest management using options such as reduced impact logging, longer rotations, mixed ages and species; and (iv) managing harvested agricultural & forest products like use of forestry products for bioenergy to replace fossil fuel use, tree species improvement to increase biomass and carbon sequestration. Other important elements that are to be made part of policy-based decisions are forest carbon market (compliance & voluntary), appropriate methods for carbon accounting with region specific principles, carbon pricing, and quantified influences of other unforeseen universal drivers (both climate & human driven. To achieve best results, it is always recommended to opt for three safe strategies, (i) comparing uncertainties/ assumptions adopted by scientists (ii) best carbon-efficient uses of wood to save the most tons of CO_2 per cubic meter harvested; and (iii) farm & forest-management practices that increase both the amount of physiological constraints, such as trees living shorter lives as their growth accelerates and soil fertility falling in mature forest lands.

5. Recent Deeds and Future Roads

5.1 Recent Initiatives/Approaches in India

India sustained to increase its CO_2 emissions to 2.47 billion tons in 2015, which was 5.1% more than in

2014. This growth rate is alike to the one detected for 2013 and 2007, and a little below the average growth rate of 6.8% for the 2006–2015 period (Figure 2.2). If India continues with this average growth rate, it will surpass the total emissions in the European Union by 2020, assuming also that the European Union will decrease its emissions at the 2006–2015 average rate of 1.9% per year. India's emissions already surpassed those of the Russian Federation in 2009 and India meanwhile is a major emitting country, effectively cancelling out the emission reductions in 2015 by China and the United States. However, India's per capita emissions of 1.9 tons CO_2/cap are more than three times lower than the average per capita emissions in the EU and even lower than the average per capita emissions in developing countries (T. V. Ramachandra and Shwetmala, 2012; R. Miner and C. Gaudreault, 2016).

India's GHG emission increase seems to be coupled with its GDP growth. In 2015, GDP continued to increase, with a growth rate of 7.6%, compared to 2014. This economic growth confirms a further acceleration of India's economy over the past three years, and adds to the average growth over the past decade (2006–2015) of 7.4% (World Bank, 2016). Country is actively marching ahead to contribute her share in global efforts towards climate-based missions/ targets via carbon management. It has paid merely 6.3 % of all global CO_2 emissions in 2015, and researchers have well said that global carbon emissions did not grow last year and the projected rise of only 0.2 % for 2016 marks a clear break from the rapid emissions growth of 2.3 % per year in previous decade. Moreover, on the other side the global carbon budget analysis showed that, in spite of a lack of growth in emissions, the growth in atmospheric CO_2 concentration was a record-high in 2015, and could be a record again in 2016 too due to weak carbon sinks. Part of the CO_2 emissions is absorbed by the ocean and by trees. With temperatures soaring in 2015 and 2016, less CO_2 was absorbed by trees because of the hot and dry conditions related to the El Nino event. If one compares the situation in Asian part of globe, India is performing well and amply safe to safeguard carbon emissions and utilizing its reduction potential to a best possible extent.

T. V. Ramchandra and Shwetmala (2012) have provided valuable highlights on carbon magnitudes with relative share of forests (vegetation, soil) and agriculture (soil) sectors for different states of India. Their estimates reveal that forest biomass store around 74% of total carbon stored. India has a large spread of farming & forest areas being about 1120090 and 677080 Km^2 respectively, where carbon storage potential varies greatly from one state to another (Fig. 3).

The Green India Mission' use to be one of the core national mission adopted under the Indian National Action Plan on Climate Change (NAPCC), encompassing wider areas (even urban, shifting cultivation areas) and addressing dual aspects of mitigation and adaptation. The intention is to double India's existing greening efforts through scaled up investments and convergence with other related missions (MoEF, 2011). It has an estimated cost nearing US$7 billion, and aimed towards a 5 million hectare increase in forest and tree cover by 2022 with enhancement of tree cover on over 0.2 million hectares of urban and peri urban areas by creation of new agroforestry and social forestry assets (K. S. Shrivastava, 2014). Much of the opportunity to store carbon through afforestation in India are being occurred through agroforestry on agricultural lands due to the fact that majority of Indian farm lands is being intensively cultivated.

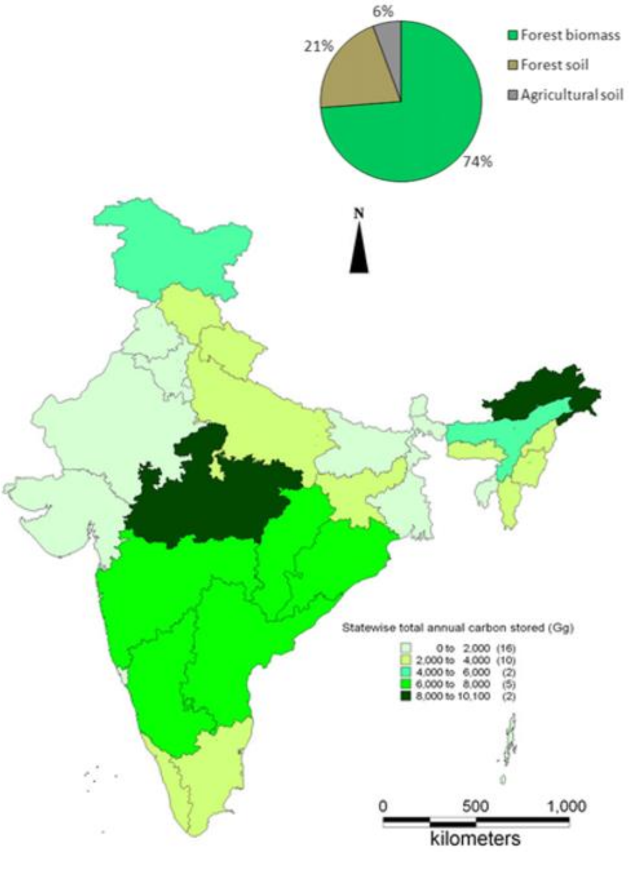

Fig.3 Annual carbon storage in different states of India (*Source : T. V. Ramachandra and Shwetmala, 2012*)

'New Forestry Policy' is another big effort by Indian government to conceive, confine, and create new forest policy-2016, that have amply considered many of the issues and concerns (integrating climate change concerns in forest management, embedding forest hydrology and hydro-geology in forest education/ planning/management/research/training, creating a pool of carbon with delayed release, massive afforestation and reforestation to create an additional carbon sink, intensive agro-forestry and farm forestry, logical dealing (keeping carbon dynamics in focus) of sensitive ecosystems such as coastal/marine/ mangroves/temperate/sub-alpine forests/western and eastern Ghats etc., harnessing technological potentials (digital, electronics, computers, IT ICT, GIS, RS etc).

5.2Harnessing Potential of Agro Forestry

Trees on farms have the potential to improve productivity in two ways. Tree-crop combination can increase the amount of water that is used on farm and can also increase the productivity of water that is used by increasing biomass of trees or crops produced per unit of water. Supportive evidences are well established at global scale (Table 3) including similar facts from semi-arid India (J. K. Murthy *et al*., 2013). Land use management measures may further add the benefits. Further, land such as bund and avenues that are hitherto not cultivated would increase the tree cover of the landscape (MoEF, 2011). There exists plenty of carbon stocks in agroforestry systems of India, which occurs both belowground (in the form of enhancement of soil carbon plus root biomass) and aboveground (as carbon stored in standing biomass). Estimates on carbon sequestration potential varies widely depending on the biomass production (D. N. Pandey, 2007). In a study on poplar based agri-silvicultural system, total biomass in system was found 25.2 t/ha, 113.6% higher than sole wheat cultivation, where net carbon storage was 34.61 tC/ha compared to 18.74 tC/ha in sole wheat cultivation (S. K. Dhyani *et al*., 2009). The variability of carbon storage potential is greatly governed by eco-region, soil-vegetation-cover complexes/system (Table 3) and more dominantly by soil types/groups (Table 4).

Table 3: Carbon storage potential of agroforestry systems across World's eco-regions

Continent	Eco- region	System	Potential (Mg C ha^{-1})
Africa	• Humid tropical high	Agro-silvicultural	29-53
South America	• Humid tropical • low dry lowlands		39-102 39-195
Southeast Asia	• Humid tropical • dry lowlands	... do ...	12-228 68-81
Australia	• Humid tropical low	Silvi-pastoral	28-51
North America	• Humid tropical • high humid tropical • low dry lowlands	... do ...	133-154 104-198 90-175
Northern Asia	• Humid tropical low	... do ...	15-18

Keeping in view the facts that trees absorb carbon dioxide from the atmosphere, and wood can be a substitute for fossil fuels and carbon-intensive materials such as concrete and steel, the best way to manage forests to store carbon and to mitigate climate change is hotly debated. In the past few decades, the world's forests have absorbed as much as 30% (2 petagrams of carbon per year; Pg C year−1) of annual global anthropogenic CO2 emissions about the same amount as the oceans. Much has been learned about the carbon cycle in forests, but there are still too many gaps in our knowledge. To make good decisions about how to manage forests for climate-change mitigation and whether to harvest or to conserve trees, we must better understand the cause and future behavior of relevant carbon sinks.

Table 4 Carbon stock distribution by soil order in India for varied soil depths

Soil Orders	Soil Organic Carbon (Pg)*		Total Carbon (Pg)*	
	0–30cm	0-150cm	0–30cm	0-150cm
Entisols	0.62	2.56	1.51	5.42
Vertisols	2.59	8.77	3.66	14.90
Inceptisols	2.17	5.81	2.79	12.85
Aridisols	0.74	2.02	2.14	15.42
Mollisols	0.09	0.49	0.09	0.56
Alfisols	3.14	9.72	3.30	14.20
Ultisols	0.20	0.55	0.20	0.55
Total SOC (Pg)	9.55	29.92	13..69	63..90

Source: T. Bhattacharyya et al., 2005. * $Pg = 10^{15}g$

5.3 Way forward

Coping with the adverse impact of climate change on farms and forests will require careful management of natural resources like soil, water and biodiversity. Carbon sequestration on such farms or forests remains a win-win approach which can easily deal both adaptation & mitigation aspects. Restoration of waste and degraded lands and ecosystems through adopting improved management practices can enhance carbon budget and thus improve soil quality & health. Improving organic matter in soil will have to be another futuristic action to increase water holding capacity of soil which in turn helps to cope up with intermittent dry spell, and facilitate release of nutrients in more judicious manner, once smart agriculture practices such as conservation agriculture, inter cropping, crop rotations, improve cultivars, integrated nutrient management, soil & water conservation, watershed management, can sizably increase carbon sequestration

From futuristic strategy point of view 'carbon stocks' needs to be preserved by ensuring net additions in forest/tree cover, rather a one-way depletion. Based on actual & projected trends of investments in farms & forestry sectors different scenarios of the future carbon stocks needs to be well understood (even hypothetically, if data is constraint). From futuristic carbon sequestration potential (only from agricultural farming) point of views, India happens to be at 2nd position holder in world after USA, with carbon magnitude that is equivalent to removing of 46 million cars per year. CCS might be another vital climate defense technology for coal-rich countries/locations provided an accurate prediction are made on existing potential storage formations keeping in view the geological subsurface/geographic match of these sinks with present and projected CO_2 emissions.

Altogether the future of globe is going to be evaluated in terms of carbon-based economy, where science-based plans and activities remans an inevitable ingredient. It altogether requires location specific operational efforts to work upon new frontiers of science. India's 14th Finance Commission, which is appointed every five years to define the financial relations between India's central government and states, recently recommended adding forest cover to the tax formula, giving it a weight of 7.5% within the overall formula, where other factors have their own weight (e.g. accompanying population in 1971 @17.5%, population in 2011 @10 %, fiscal capacity @50% and land area of state @15%). It clearly paved an innovative way telling states that the share of tax revenue that each state receives will depend in part on how much forest they have maintained, as monitored by India's 2013 Forest Survey. Further research needs could be set on issues like, identification and characterization of natural analogues, site specific assessments of storage formation integrity, assessment of potential leakage pathways through fractures and porous media, potential impact on water resources, surface ecosystems, potential for solubility, mineral trapping and impacts on formation porosity, potential for catastrophic releases, characterization of soil micro-organisms & potential ecological impacts, monitoring and remediation methods/models, development of geophysical monitoring techniques, evaluation of impacts due to co-recovered acids gases/ contaminants

Conclusion

Farms and forests play an important role to govern and regulate the global carbon balance. They act in both the roles, namely the 'carbon sources' and 'carbon sinks'. They have vast potential to form an important component while planning and implementing any effort to combat adverse climate issue. Carbon flows from these two big sectors comprise a significant part of overall global GHGs emissions. In accordance to prevailing conditions, the carbon accounting on farms and forests can be divided into three specific arrangements, (i) stock accounting to assess the magnitude of carbon stored in given ecosystems at a single point in time, (ii) emissions accounting to assess the net GHG emissions to the atmosphere resulting from farms/forests, and (iii) generalized emission reductions to assess the decrease in emissions from project or policy activities. Forest carbon accounting could be very much useful for identifying the carbon-density of areas and thus providing information for low-carbon-impact land use planning. It can vastly facilitate to prepare territories for accounting and attaining safe emissions from these sectors.

Accounting GHGs commonly referred with a popular term 'carbon footprints', that used to be a principle component of climate change impacts having big influences on many sustainability policies of agrarian farms and forests. Such sustainability in the context of ecological concerns, not just climate change but also other environmental issues, like pollution or depletion of natural resources, keeping focus towards bringing down the risks. But how big and real is this risk? We need to rethink and make a strategic SWOT analysis to bring upon the appropriate models, cyclic impacts, technologies, and services cutting across several sectors (rainwater, irrigation water, renewable energy, transportation, conservation-based materials & practices, integrated management of land-water-vegetation etc.). CCS and agro forestry based hi-tech options are well established opportunities for majority of locations in world. India too have marched ahead to accomplish the due milestones in this regard with vast untapped potential. No doubt, there remains some of the bottlenecks in harnessing such potentials, but they are clearly attainable.

World is standing at a crossroads when it comes to forests and climate change. Need of the hour is to go for the better possible practices in carbon accounting both for farms and forests, in particular the transparency in methods and accuracy and precision in accounting for public and political acceptance of resultant estimates. The year 2014 saw the most payments for forest carbon offsets ever. India has shown ample potential for capturing carbon via agro-forestry and social forestry means by having a sound synergy among agrarian, forest and grassed lands. Even the hydrological and other land and water-based interventions partake greater scope to get linked with carbon-based strategies and interventions at micro scales. The gist on present and futuristic magnitudes of carbon in soils, forests and other ventures for Indian conditions as offered in this thought-provoking article, have made it clear that by conceiving and executing an integrated plan for tackling sensitive issue of carbon assessment, management, dynamics, market and management in a region-specific manner certainly leads to harness many benefits (productive as well as protective) out of it.

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