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Carbon Economy in Indian Agriculture

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Preface

Climate change and resulting weather extremes are the two most important issues confronting mankind today. A dramatic increase in the atmospheric concentration of greenhouse gases (GHGs) is said to be the principal factor contributing to climate change. Hence, efforts are being made to reduce the GHG emission in all sectors of the economy. Among the different sources, the contribution of agriculture, forestry and other land use changes (AFOLU) to total GHG emission is 24% (global) and 17.6% (India). At the same time, there is a huge carbon sink potential in this sector. Globally, soil carbon sequestration has about 89% of the total mitigation potential in agriculture sector.

The established linkage of GHG emission with climate change has led to international negotiations and the recognition of carbon (C) as a tradable commodity. Agriculture, being the major land use, occupying about 55% of the total geographical area in India, can contribute to improve the C sink potential through wide adoption of climate friendly management practices. Our motto should be to produce more with a *low carbon footprint* and less damage to the environment. Agricultural practices with a low C foot-print can be a triple win in the form of enhanced adaptation, increased mitigation and stability in the food security and sustainability in the country.

There is a need to address the issues and constraints and devise ways of achieving the large scale adoption of climate friendly agricultural practices. Keeping this in view, a Brainstorming Session on *"Carbon Economy in Indian Agriculture"* was organized by the National Academy of Agricultural Sciences on 01 February, 2014. In addition to eight presentations made in the relevant topics, there was active participation of 28 distinguished experts from ICAR, SAUs and Ministry of Agriculture, Govt of India. I am of the opinion that the recommendations in the policy paper, derived out of the deliberations, will be acted upon by the stakeholders and will show the required path to enable Indian agriculture contribute to achieve C economy in itself and add to improve the C economy of the country.

On behalf of the Academy, I would like to compliment the Convener, Dr. A. Subba Rao, Former Director, Indian Institute of Soil Science (IISS), Bhopal and the Co-Conveners, Dr (Mrs.) Sangeeta Lenka, Scientist, IISS and Dr. N. K. Lenka, Principal Scientist, IISS for their valuable contributions. I also sincerely thank all the speakers and participants of the Brainstorming session, Reviewers and the Editors of the Policy Paper for their sincere efforts.

S Ayyappan
President

Carbon Economy in Indian Agriculture

1. PREAMBLE

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 global mean surface air temperature has increased by about 0.74 ˚C over the last 100 years and is projected to rise by 0.3–2.5 ˚C in the next fifty years and 1.4–6.4 ˚C in the next century (IPCC, 2007), and the warming will continue beyond 2100 (Pachauri, 2013). The radiative forcing of CO_2, CH_4 and N_2O is very likely (> 90% probability) increasing at a faster rate during the current era than any other time in the last 10,000 years which is attributed to the increase in the global abundance of the three key GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The concentration of CO_2, CH_4 and N_2O has increased markedly by 30, 145 and 15 percent, respectively as a result of human activities since Industrial Revolutions in the past (IPCC, 2007).

The role of GHGs in the climate change has led to international negotiations, resulting in recognition of carbon (C) as a tradable commodity and the growth of the global C market. As the earth's atmosphere has a finite C space, emission trading schemes or C trading has come into play with the ultimate objective of halting and reversing global warming and climate change. There are efforts to reduce the C footprint in all spheres of life including agriculture and food production sector. In India, agriculture sector contributes about 17.6% of the total GHG emissions (Fig. 1). At the same time, there is a huge C sink potential in this sector including land use, land use change and forestry sector (LULUCF). Globally, soil carbon sequestration has about 89% of the total mitigation potential in the agriculture sector (IPCC, 2007).

Low-carbon agriculture refers to the method or practice of agriculture, that is less a source and more a sink of C. A practice having a low C or high C footprint is largely decided by the management practices adopted. However, identification and adoption of best management practices (BMPs) with low C footprint (i.e., low C emission and high C sink) are needed for different agro-ecological regions of the country. It is an important strategy to facilitate/promote adoption of BMPs and in this context treating the soil and terrestrial C as a commodity, can provide the much needed incentives to promote adoption of BMPs. In view of the likely future developments, it is high time to trade a soil sequestered C similar to other farm

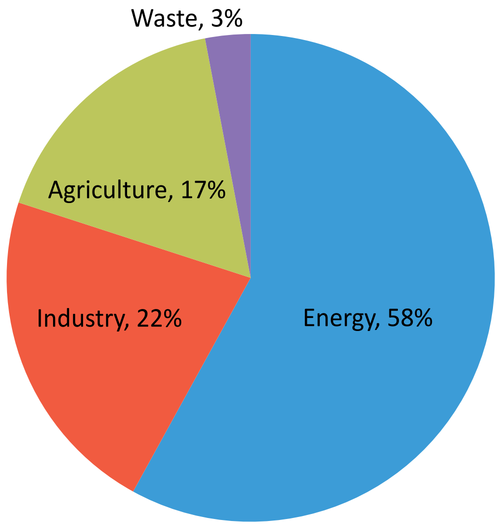

Fig. 1. Sector wise share of GHG emissions in India in the year 2007 (INCCA, 2010)

commodity. Further, an agricultural practice with a low C footprint can be a win-win strategy for India and its farming community because of the growing C market as well as the multiple co-benefits associated, such as improvement in soil properties, soil health and increase in the crop production sustainability.

This Policy Paper is an outcome of a Brainstorming Session on Carbon Economy organized by the National Academy of Agricultural Sciences (NAAS) on 1st February, 2014. The key areas of agriculture sector offering scope to improve the C economy, the constraints involved and the trade-off issues are discussed highlighting policy options, researchable issues and the action points for implementation.

2. GREENHOUSE GAS EMISSION FROM INDIAN AGRICULTURE

As per the estimate made by the Indian Network on Climate Change Assessment (INCCA), in the year 2007, the GHG emissions from agriculture sector constituted 17.6% of the total net CO_2 eq. emissions from India. The total emission from agriculture sector was 334.41 million tons of CO_2 eq. (INCCA, 2010). The emission from Indian agriculture primarily emanates from five principal activities, *viz.* enteric fermentation from livestock, rice cultivation, manure management, agricultural soils and burning of crop residues. The LULUCF sector covering emissions and removals from changes mainly in forest land, crop land and grasslands, was a net sink, which sequestered 177 million tons of CO_2. Thus, the LULUCF sector plays an important role in regulating the emission profile from the agriculture sector and provides avenues for increasing the sink.

India's per capita CO_2 emission was 1.5 tons / capita in 2007. The total GHG emission from all sectors has increased at a compounded annual growth rate of 2.9% from 1229 million tons of emission in 1994 (as per the 1st National Communication to the UNFCC), to 1728 million tons in the year 2007. However, the contribution of the agriculture sector to the total emission has reduced from 27.6% in 1994 to 17.6% in 2007. The emission from enteric fermentation in livestock was 212 million tons of CO_2 eq, constituting 63.4% of the total emission from agriculture sector in India. Manure management and rice cultivation contribute 2.44 and 69.87 million tons of CO_2 eq. respectively. The total emission from the other two sources, *viz.* N_2O production from agricultural soils, and CH_4 and N_2O emission from crop residue burning is 50.0 million tons of CO_2 eq.

About 34 million tons of CO_2 eq., 99% of which takes place through CO_2, is emitted from the energy use in agriculture and fisheries sector (though in the INCCA report, the figure is considered under Energy sector). If the figure of 34 million tons is considered as emission under agriculture sector, the relative contribution from agriculture energy used to the total emission from agriculture is about 9%. Thus, in relative terms, the major contributors are enteric fermentation, followed by CH_4 emission from rice cultivation, N_2O emission from agricultural soils and the energy use in agriculture and fisheries sector.

During 2007, the major land use in India was crop lands with a share of about 55%, followed by forest lands of about 21%. Even though it influences the GHG emissions, a significant influence on the C budget from the two land uses occurs through increase in C sink, particularly through C sequestration.

3. SCOPE FOR 'C' ECONOMY IN INDIAN AGRICULTURE

The C economy in Indian agriculture can be improved through two principal modes (1) by reducing the total emission, and (2) by increasing the C sink. Under these two modes, the major areas with scope for improving the C economy are outlined below

i. 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). Globally, livestock produces about 80 million tons of enteric CH_4 annually. Most of the CH_4 from ruminant livestock originates from microbial fermentation of carbohydrates in the rumen and the lower digestive tract, referred to as enteric CH_4 emission. CH_4 production in ruminants depends upon quality, quantity of feed, type of animal and digestibility of pasture and feeds. 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 CH_4 (Sejian et al., 2011).

Methane mitigation strategies can be broadly divided into preventive and 'end of pipe' options. *Preventive measures* reduce C / nitrogen inputs into the animal husbandry, generally through dietary manipulation and, although a reduction in the volume of CH_4 emitted per animal may result, this is often secondary to the primary objective of improved production efficiency. Alternatively, '*end of pipe*' options reduces - or inhibit - the production of CH_4 (methanogenesis) within the animal husbandry. Any reduction strategy must be confined to the following general framework viz., development priority, product demand, infrastructure, livestock resource and local resources. The attractive emission mitigation projects must balance the needs in all of these areas, that no element creates a constraint on continued improvement in production efficiency, and the resulting CH_4 emissions reductions.

ii. Manure management

Management decisions about manure disposal and storage affect emissions of CH_4 and N_2O, that are formed during decomposing manures. Although CH_4 and N_2O emissions from manure management are minor, manure itself is an important contributor to emissions because it is either applied on cropland as organic fertilizer or directly deposited by grazing animals in pastures. In India, manure management is responsible for emission of 120.44 thousand tons of CH_4 and 0.08 thousand tons of N_2O annually (Sharma et al., 2011). Biogas generation from the cattle dung reduces the net emission under the particular area, despite efforts are needed to make the biogas technology popular.

iii. Rice cultivation

The acreage under rice cultivation in India is estimated at about 44.0 million hectares, mainly planted in wet monsoon or irrigated systems by flooding and puddling the fields. The rice fields are a major source of emission of GHGs as CH_4 and N_2O. 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. An extensive methane measurement campaign was coordinated by the National Physical Laboratory in 1991. Measurements were undertaken in major paddy growing regions of the country under different rice environments for the whole cropping period. Emission of CH_4 from paddy cultivation in India was estimated at about 4 million tons/year (Gupta et al., 2009).

iv. Soil C sequestration

Soil C sequestration refers to removal of CO_2 from atmospheric pool and its storage as soil organic matter. Globally, potential for C sequestration in soils over the next 50 year period is estimated at 2 to 3 billion tons C yr^{-1} through improved management of existing agricultural soils and restoration of degraded lands (Lal, 2009). This would correspond to about 9-12% of the anthropogenic CO_2 - C produced annually. 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). In India, ICAR and NAAS have estimated about 121 million hectares to be degraded lands (Maji et al., 2010), that are greatly depleted in SOM, and also cover the salt-affected wastelands. It has been suggested that by reclamation of salt-affected wasteland in India, up to 2 billion t C could be sequestered (Lal, 2004). There is a considerable uncertainty in the estimates, concerning both C flux rates and soil C storage capacity. Since soils have a finite capacity to store additional C, the total amount of C sequestered and the estimates there of depend on the time horizon considered. Further, permanence of C sequestered in soil depends on the continuation of the recommended management practices.

v. Field 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 field for sowing of the succeeding crop (NAAS, 2012). In some parts of India post-harvest agricultural wastes are burnt in the field to prepare the field for the next crop. Farmers prefer this practice to dispose of the crop residues of rice, wheat, maize and sugarcane. The problem of on-farm burning of crop residues has intensified in recent years and is severe particularly in northwest India, where rice-wheat system is mechanized using combines for harvesting and involvement of high cost of labour in removing the crop residues by conventional methods (NAAS, 2012). Emissions of CO_2 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 addition to aerosol particles, biomass burning owing to forest fires and crop residue burning are considered as a major source of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), volatile organic compounds (VOC), nitrogen oxides and halogen compounds. Carbon monoxide is a chemically active gas in the troposphere influencing the abundance of O_3 and the oxidizing capacity (OH) of the troposphere. In India, field burning of crop residues account for 257.21 thousand t of CH_4 and 6.67 thousand t of N_2O emissions annually (Sharma et al., 2011).

vi. De-carbonization of fuel and alternate energy sources

Crop residues are being considered as a possible renewable source of energy. The assumption that the conversion of cellulosic biomass (corn stover, wheat and rice straw) has a higher potential for fuel production than grain-based ethanol needs to be objectively assessed in terms of the possible adverse effects of crop residue removal on soil quality, agronomic productivity and sustainability of soil and water resources.

Globally, 25 billion tons of CO_2 are generated by anthropogenic activities every year (IPCC, 2007). 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.

The IPCC 4th Assessment Report has observed that increasingly, agricultural crops and residues are seen as sources of feed stocks for energy to displace fossil fuels. A wide range of materials have been proposed for use, including grains, crop residue, cellulosic crops (e.g., switch grass, sugarcane), and various tree species. These products can be burned directly but can also be processed further to generate liquid fuels such as ethanol or diesel fuel (Richter, 2004). Such fuels release CO_2 when burned, but this CO_2 is of recent atmospheric origin (via photosynthetic carbon uptake) and displaces CO_2 that otherwise would have come from fossil C. The net benefit to atmospheric CO_2, however, depends on energy used in growing and processing the bioenergy feedstock (Spatari et al., 2005). Biofuels are an important strategy towards an attempt to wean the civilization away from its pathetic dependence on fossil fuel. Towards achieving that goal, it is necessary to identify alternate sources of lingo-cellulosic materials that are appropriate ecologically, feasible environmentally and sustainable pedagogically.

Major issues involved

There are several technological options to reduce emission of GHGs from Indian agriculture. In spite of their theoretical importance in C economy, there are a number of practical considerations and constraints in implementing the alternate methods or practices (Table 1). Further, there are also trade-off issues, that need to be looked into in each before making clear cut recommendations for farmers' adoption.

4. ADDITIONAL BENEFITS OF 'C' ECONOMY

Carbon economy in Indian agriculture is regulated by the factors discussed under section 3.0, and their potential is limited by several technical, socio-economic and

Table 1: Potential and constraints of Indian Agriculture to mitigate GHG emission

Mitigation option	Mitigation %	Constraints
1. Methane from rice field		
Intermittent drying	25-30	Assured irrigation
Dry seeded rice	30-40	Machine, herbicide
SRI	20-25	Labour, assured irrigation
2. Methane from livestock		
Balanced feeding	5-10	Cost, open grazing
Feed additives	5-10	Cost, Biosafety
Efficient animals	10-20	Cost, acclimatization
3. N_2O from soil		
Site specific N use	10-15	Awareness, Fertilizer policy
Nitrification inhibitors	10-15	Cost, Incentive
4. Carbon sequestration in soil		
Conservation Agriculture	15-20	Continuity, small holding
Organic farming	15-25	Manure availability, cost

Source : H. Pathak (2014)

feasibility constraints. 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.

As per the study in dry land soils of India, every Mg ha^{-1} increase in SOC stock in the root zone, an increase in grain yield (kg ha^{-1}) of 13 for groundnut, 101 for finger millet, 90 for sorghum, 170 for pearl millet, 145 for soybean, 18 for lentil, and 160 for rice (Srinivasarao et al., 2013) was observed. The yield benefits are substantial with more SOC stock in the soil profile. However, the effect of increase in C sequestration on crop productivity depends on the existing soil organic C level. In irrigated wheat, the contribution of 1 ton SOC ha^{-1} in the plough layer to wheat productivity ranged from 15 to 33 kg ha^{-1} across SOC concentration ranging from 3 to 9 g kg^{-1} soil (Benbi and Chand, 2007). Thus, the impact of soil carbon sequestration on agronomic productivity and advancing food security cannot be over emphasized.

Higher SOC content also promotes water productivity, reduces energy use in tillage operations and provides sustainability to crop production under aberrant weather conditions. In other words, a higher SOC content can enhance the mitigation and adaptation effects to climate change conditions. Each ton of sequestered organic C in the plough layer has been reported to compensate for 4.7 kg fertilizer N ha^{-1} in irrigated wheat (Benbi and Chand, 2007). This indirectly results in reducing emissions related to fertilizer N production and application. Direct and indirect emissions of C through fertilizer N, P, and K use range between 0.1 and 1.8 kg C per unit nutrient used (Benbi, 2013). 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 soil and soil C.
- 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 soil C level by regular additions of organic inputs.

5. LEARNING FROM INTERNATIONAL EXPERIENCE

Carbon trading in agriculture sector has been in practice in countries like USA, Australia, New Zealand and Canada through voluntary C markets. The Chicago Climate Exchange (CCX) was the largest C trading scheme, that included agriculture and specifically no-till farming for C trading, although since 2010, there are no transactions in the CCX. The C-Lock Technology, Canada provides C credits earned from soil C sequestration. In Australia, the Carbon Farming Initiative (CFI) has been initiated by the Australian government to generate credits that are recognized for Australia's obligations under the Kyoto protocol. This included credits earned from activities such as reforestation, fire management, and reduction in pollution from livestock and fertilizers. In Africa, the World Bank through its bio-carbon fund is promoting the Kenyan Agricultural Carbon Project and showcasing it as a triple win of mitigation, adaptation and food security for small scale producers. The project is operated in two districts of Western Kenya and is being operationally run by Swedish Cooperative Centre – Vi Agroforestry Program (SCC – ViA), where the Sustainable Agricultural Land Management Technology (SALM) is adopted by 60,000 farmers extending over 45,000 hectares of crop area and the C credits are decided by acreage of adoption of the best management practices. The SALM methodology has also been approved by the Verified Carbon Standard, the approval of which is necessary for taking up any C credit project. The SALM practices in the Kenyan project include best management practices in croplands (cover crops, crop rotation, mulching, improved fallows, compost management, green manure, agro-forestry, organic fertilizer, residue management) and rehabilitation of degraded lands (World Bank, 2014).

Despite the above, the agricultural C credits are less attractive and of lower value because of high transaction costs and leakages involved. High uncertainties are involved in measurement, and in the value of permanence. Agricultural offsets also are problematic from additionality and permanency perspective, based in part on farming's multifunctional character. Additionality generally refers to whether or not a carbon sequestering activity would have occurred without the payment, but in agriculture determining additionality can be complicated. Thus addressing the issues of defining baseline, additionality, leakage and permanence in agriculture is necessary to earn carbon credits. Measuring carbon captured in soils presents several problems. Variations in soil type and practice mean considerable uncertainties regarding the amount of sequestered carbon from plot to plot. Thus, standardization of good methodology for soil carbon determination is also essential to get the desired level of accuracy in carbon offset markets.

Learning from the international experience, specific activities pertinent to Indian agriculture need to be defined for framing a workable scheme of C trading.

6. RECOMMENDATIONS

A. Research and development issues

Full C cycle analysis of mitigation measures: A full carbon cycle analysis must be used to calculate net C sequestration based on all significant C exchanges with the atmosphere. There is a strong need to estimate the net C sequestration taking into consideration C costs (hidden C costs) of all the inputs (eg. fertilizer, pesticides, tillage operation and irrigation). Thus, the rates of gross C sequestration coupled with full C cycle analysis will provide better estimates of current and potential net C sequestration at the country level. The transition to low-carbon agriculture requires identification of appropriate systems and management practices for each production system based on the resource endowments and the resource requirements. Developing such a strategy at the national level should be based on sound scientific data about the carbon footprint / life cycle assessment of the mitigation measures during the whole duration of the crops and cropping systems.

Emission estimates: Accurate emission estimates are needed for different agricultural enterprises, without that the emission trading scheme (ETS), that include agricultural emissions would lack the certainty and reliability necessary for market credibility and would fail to send the right price signals. This should be done by developing the emission coefficients under Indian conditions for all activities such as machinery for tillage, threshing and harvesting, pumps for irrigation, the emission involved in manure preparation, fertilization of crops and the emission during the crop growing period.

Multi-pronged strategy: Carbon economy in Indian agriculture can be achieved through interventions needed to improve the efficiency factors in water, nutrient and energy use. A soil with higher C storage leads to greater water and nutrient use efficiency and also reduces the energy requirements during tillage operations. Higher nutrient use efficiency can reduce the requirement of higher fertilizer application rates and thus indirectly improving the C and energy economy through a reduction in the mineral fertilizer demand. Similarly, modification of micro-climate through small interventions as mulching can help in improving the water use and C economy.

Trade-offs among mitigation measures: For reducing emission of the contributing GHGs, different interventions are available. However, under field conditions their applicability needs to be judged based on the trade-offs among themselves. For instance, alternate wetting and drying can reduce the CH_4 emission from rice fields and also reduce the water consumption, but increases the N_2O emission, which has a higher global warming potential than CH_4. Further, farmers may also be averse to drain water from their fields in the rain-fed regions keeping in view the uncertainties in the rainfall during monsoon season. Hence, adoption studies need to be made to prescribe the best available technologies keeping the totality into account.

Methodology for monitoring for agricultural / soil C credits: Even though countries like USA, Australia, China and Vietnam have developed systems for carbon credits from agricultural based enterprises, India lacks one. To improve C economy, the net reduction in the CO_2 equivalent emission (after discounting the sink) should be properly monitored and priced. As of now, there is no standard methodology for monitoring and verification of C credits that can be earned from crop and crop based activities including soil C sequestration. Identification of some benchmark sites/ systems in each agro-ecological region should be done for repeated measurements of change in soil C stock over time.

Modeling and remote sensing for emission and sequestration monitoring: The monitoring of emission and C sequestration physically on a large scale is practically and economically not feasible. Thus, there is a strong need to calibrate and validate the carbon models for each agro-ecological region. These models can be used for monitoring both emission and sequestration under the dominant cropping and farming systems prevalent in the region. Some validation studies with high resolution satellite imageries can establish a sound methodology. The help of Geographical Information System (GIS) and Global Positioning System (GPS) need to be taken in the above mentioned activities.

Methodologies for measurement, reporting and verification (MRV): The MRV for agriculture C credits is complicated by several factors, some of which have been discussed above. In respect of soil C, a standard methodology need to be identified and studied for measurement of sequestered C. The methodology should also be able to track the changes in C stock over time. The measurement technologies used in research farms for controlled experiments may not be suitable for on-farm measurement because of the cost, complexity and scale issues. Thus, there is a need to develop simple measurement methodologies. Further, in case of agricultural C credits, the distinction between anthropogenic and non-anthropogenic emissions is difficult to judge. This complicates the problem of getting a good estimate of GHG emission from agriculture, particularly for land based activities.

Data generation for estimation standardization: In many cases, it is not feasible to get measured data over a sufficient temporal and spatial scale. Thus, there should be sound estimation methodologies for relatively accurate and reliable estimation of soil C sequestration and agricultural C emission, though substituting estimation for direct measurement may introduce more uncertainties. Limited studies and lack of enough data, and the complexity of modeling biological processes contribute to these uncertainties. Therefore, there is a need to generate more reliable data.

Crop residues use in agriculture: The quantum of crop residues that can be used for retention and incorporation in the soil should be optimized keeping in view the competing demand for crop residues such as fodder. The suitability of crop residues retention or incorporation in different soil types should be assessed and the impact in terms of soil C improvement needs to be quantified (NAAS, 2012).

Utilization of waste lands for C trading: We need to develop a robust programme to provide a road map for using the wastelands for C trading. This will not only provide employments to rural youths but also act as a potential mitigation option.

B. Policy issues

Incentivizing farmers for adoption of BMPs: Carbon economy in Indian agriculture can be achieved through adoption of BMPs, which can improve the utilization of water, nutrients and energy and help C build up in the soil. Though adoption of Best Management Practices (BMPs) by farmers can improve the C economy, but under field conditions farmers do not adopt them on their own. Under Indian conditions, it may not be possible to penalize the farmers for taking up wrong land uses. Rather, it will be easier if the farmers who adopt the BMPs are given incentives, which can be monitored through appropriate methodology. Further, the agricultural

C market is highly volatile and therefore soil C credits attract much low unit price. These two factors make the issue of C offset strategy not an attractive proposition. Instead, a predictable incentive to the farmers who go for adoption of best farming and climate smart practices can go a long way in wider adoption of BMPs and help in addressing the global warming issues. Small farmer groups and NGOs can help in monitoring and delivering incentives to the farmers. A mechanism to provide incentives to farmers for accrued C benefits through the adoption of BMPs needs to be developed. This mechanism will improve C economy but also sustains better soil health while, enhancing crop productivity.

Policy on soil and water conservation and agroforestry on a watershed scale: Among several options, the potential of degraded lands for C sequestration is the highest. Hence, activities which restore degraded land such as soil and water conservation measures, the adoption of agroforestry systems such as silvi-pastural and horti-pastural systems, afforestation and planting of N-fixing tree species should be taken up for land treatments on a watershed scale. The selection of the species and systems should be location and climatic region specific. As the role of agroforestry in C sequestration, both in vegetation and edaphic pools, is higher than arable cropping systems, a suitable national policy is required to promote and ensure a phase-wise and time framed adoption of agroforestry systems (location specific) in different agro-ecological regions of the country.

Policy on crop residue burning: A suitable policy needs to be taken up to reduce crop residue burning, which can be attempted through legal restrictions or through incentive to farmers for some years, to break the on-going habit. Policy support should be given for suitable machinery for cutting of crop residues, composting and biological cultures for composting of crop residues.

Geo-referenced inventory of crop residues: A geo-referenced inventory of crop residues generated and in each cropping system should be developed (NAAS, 2012)

Carbon offset program in tradable areas: A carbon offset program can be successful in agriculture sector only if the carbon credits to be traded are in a bulk quantity, easily measurable and there are buyers to buy the credits. Thus, measures at the government level to effectively integrate farmers into carbon trading processes are needed. For example, if conservation agriculture is considered as a tradable activity, then the scale of adoption should be sizeable, that a pool of credits is generated. Similarly, degraded land restoration measures and soil health improvement programs can be brought into the C trading network. Pooling of many smaller parcels of land under mitigation activities should be aimed at, as well as different activities other than farming having potential for credit earning should be clubbed (eg. Biogas, improved domestic lighting etc.). The non-profit institutions and government should take responsibility for capacity building of community representatives for monitoring, supervision and enhance capacity to measure and monitor carbon stocks and emission reduction at a low cost. We need to establish an inter-ministerial institutional mechanism for strategic use of soil resources for C trading.

Pilot schemes to be initiated: To verify and explore the possibility of the agriculture C offset program in India, there is a need to launch pilot scale projects at the earliest, involving lead research Institutes along with NGOs. Lessons should be learnt from the international experience of Kenyan Agriculture C project funded by World C fund (World Bank, 2014). A network of ICAR Institutes, especially NRM Institutes, needs to work on various aspects of C economy. There should be a "National Green Research Fund" for strengthening research on the C economy in agriculture.

Linkages with National Flagship programs: Several rural development programs are run by MoRD and Ministry of Agriculture, Govt. of India, such as Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) scheme, Rashtriya Krishi Vikash Yojana (RKVY), National Horticulture Mission (NHM), Integrated Watershed Management Program (IWMP), National Mission on Sustainable Agriculture (NMSA) etc. in which soil carbon restoration activities can be integrated. For instance, bund planting of legume fodder crops and green leaf manuring crops, soil and water conservation activities, afforestation in waste lands and common lands can be brought under the umbrella of the National programs.

ACTION POINTS

a) Policy options

1. Define and outline technologies and management practices in agriculture and allied fields which provide potential carbon offsets and improve C economy.
2. Alternate abatement policies in agriculture to incentivize farmers adopting carbon neutral practices.
3. Carbon offset policy for agriculture: Offset policy must recognize that, to be successful, millions of individual farmers in India must take action, annually, to both create and maintain the sink. For offset credits being relevant to farmers, policies need to be developed that maximizes the value of carbon offsets at the farm-gate.

4. There is a need to transfer and disseminate low-carbon technology, that is, to address externalities and market failures related to innovation.
5. Identification of barriers to carbon-efficient behavior and investment, in particular to unlock the existing energy efficiency potential.
6. Clear-cut policy on crop residue management especially discouraging residues burning and using the same in conservation agriculture should be formulated.

b) Implementation

1. Enhancing national capacity on C trading in agriculture through the establishment of inter-ministerial institutional mechanism to help strong C trading in agriculture.
2. Assessment and documentation of C sequestration potential in different agro-eco-regions of the country depending upon the prevailing farming and management systems.
3. Disseminating tradable activities that can earn credits to large individual farms and also to small farmer associations/groups. The possible tradable activities in croplands include cover crops, crop rotations, mulching, improved fallows, compost management, green manure, agro-forestry, organic fertilizer, residue management and reclamation of degraded lands.
4. Dissemination of the best fertilizer nutrient, manure, water and soil management practices among the farmers to promote low carbon economy in the country through integrating farmers, government extension agencies and non-profit institutions/ organizations.
5. A roadmap needs to be developed for reclaiming the waste lands and degraded lands and establishing agro-forestry systems. This will also generate employment to rural youths.
6. Carbon economy can also be achieved through promoting the use of alternate energy sources such as solar and wind energy in on-farm agricultural operations

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