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Carbon footprint of Indian agriculture

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The world is facing high risks related with global warming and climate change, which is a result of the "enhanced greenhouse effect" mainly due to human induced release of greenhouse gases (GHGs) into the atmosphere. Global GHG emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 mainly due to human activities (IPCC, 2007). Like most human activities, the production, processing, transport, storage and consumption of agricultural products, gives rise to emissions of greenhouse gases (GHGs). Globally about one third of the total anthropogenic increase in GHGs is attributable to agriculture and land-use change in which agriculture share about 13.5% of total global GHGs emission (Fig. 1). The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report has strongly recommended to limit the increase in global temperature below 2ºC as compared to preindustrial level (*i.e.*, measured from 1750) to avoid serious ecological and economic threats. A rise in temperature by 0.74ºC has already been recorded, and hence the world is facing challenges of mitigating climate change. This cumulative quantification of GHGs is usually represented in terms of "Carbon Footprint" defined as, "the quantity of GHGs expressed in terms of CO_2-e, emitted into the atmosphere by an individual, organization, process, product, or event within a specified boundary or entire life cycle". Carbon footprint, being a quantitative expression of GHG emissions from an activity helps in emission management and evaluation of mitigation measures. Having quantified the emissions, the important sources of emissions can be identified and areas of emission reductions and increasing efficiencies can be prioritized. This provides the opportunity for environmental efficiencies and cost reductions. In India, agriculture is the third largest contributor of GHGs, so its carbon footprint quantification is needed for development of low carbon technology.

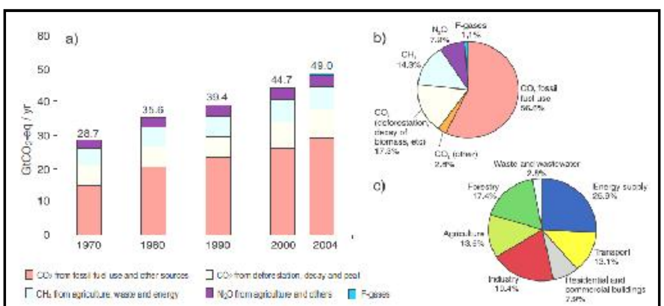

Fig. 1: Global anthropogenic GHG emissions (IPCC, 2007)

Carbon footprint calculation: Life cycle assessment (LCA) is a tool to produce complete picture of inputs and outputs with respect to generation of air pollutants, water use and wastewater generation, energy consumption, GHGs emitted, or any other similar parameter of interest and cost–benefit initiatives. For carbon footprinting purpose, LCA estimates the GHGs emitted/embodied at each identified step of the product's life cycle, technically known as GHG accounting.

System boundaries need to be defined for correct accounting of GHGs emissions. Boundary refers to an imaginary line drawn around the activities that will be used for calculating carbon footprint. To facilitate convenient accounting, tiers or scopes have been suggested (WRI/ WBCSD, 2004; Carbon Trust, 2007; BSI, 2008). Tier I includes all direct emissions, *i.e.*, onsite emissions. The tiers II and III both include indirect emissions, but tier II refers to the emissions embodied in energy production or (and) purchase, transmission, and distribution caused by the entity under consideration, but end user emissions are out of scope of tier II. Tier III tends to cover all the embodied emissions within the specified boundary. But tier III has vaguely been defined and the most carbon footprint studies limit up to tier II as it becomes too complex to estimate carbon footprint beyond tier II with accuracy.

The GHG data are translated into CO_2-eq using conversion factors provided by IPCC (WRI/ WBCSD, 2004; BSI, 2008). Some organizations and scientist report carbon footprint as carbon equivalent, but based on widespread acceptance, CO_2-eq is more popular. The unit of carbon footprint varies according to entity under consideration. Carbon footprint for individuals and dynamic processes is calculated periodically, usually annually. Therefore, the time dimension must be mentioned so as to indicate clearly the time period over which the emissions have been estimated, or if it is a one-time emission.

Carbon footprinting for agriculture : The food chain produces greenhouse gas (GHG) emissions at all stages in its life cycle, from the farming process and its inputs, through to manufacture, distribution, refrigeration, retailing, food preparation in the home and waste disposal (Fig.2 and 3).

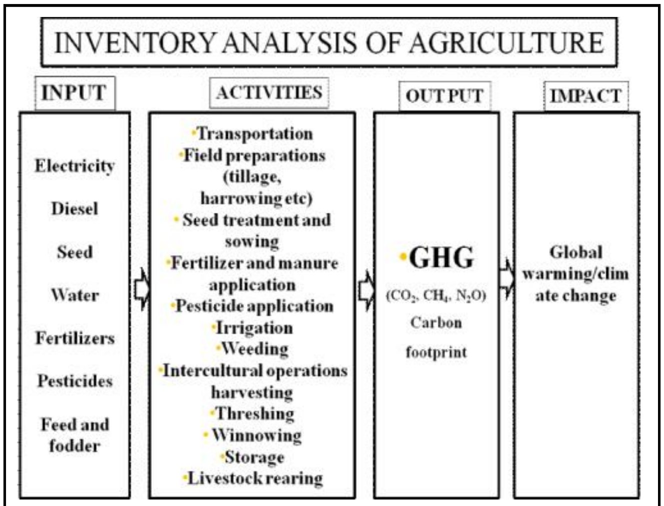

Fig. 2 : Inventory of GHG emission from agriculture

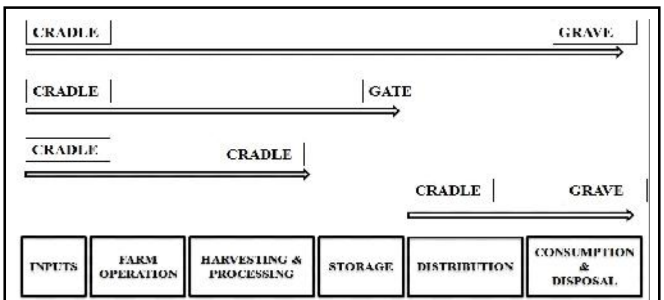

Fig. 3 : Lifecycle of agricultural product

System boundary for agricultural LCA: Agriculture is a complex system and no clear cut demarcation exit due to its multiplicity in input and out puts. System boundaries need to be defined for correct accounting of emissions associated with inputs, within field/farm activities, and after the product leaves the farm.

Sources of GHGs emission from agriculture : With reference to C emissions, agricultural practices may be grouped into primary, secondary and tertiary sources (Lal, 2004).

– Primary sources of C emissions are due to mobile operations (e.g., tillage, sowing, harvesting and transport), stationary operations (e.g., pumping water, grain drying) and direct emission from soil.

– Secondary sources of C emission comprise manufacturing, packaging and storing fertilizers and pesticides.

– Tertiary sources of C emission include acquisition of raw materials and fabrication of equipment and farm buildings, etc. Therefore, reducing emissions implies enhancing use efficiency of all these inputs by decreasing losses, and using other C-efficient alternatives.

Calculation of agricultural carbon footprint : All the GHGs emitted from primary, secondary and tertiary sources is quantified in CO_2-eq are added to calculate the Carbon Footprint of agricultural product. Emissions for on-farm activities can be calculated using default figures for energy use for field activities, converted to CO_2 equivalents (CO_2-eq). Additional emissions from soils due to field activities, as well as from crop and livestock production, can all be estimated using existing IPCC default values (IPCC, 2006). In crop production the calculated emissions may be expressed on an area basis, per ton of crop, or per unit livestock feed energy produced.

Carbon footprint of Indian agriculture : INCCA, 2007 reported that the Indian agriculture sector emitted 334.41 million tons of CO_2- eq in 2007 (Fig. 4). Estimates of GHG emissions from the agriculture sector arise from enteric fermentation in livestock, manure management, rice paddy cultivation, agricultural soils and on field burning of crop residue.

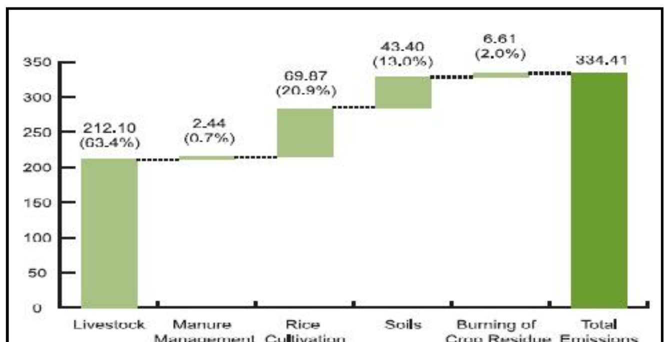

Fig. 4 : GHG emissions from Indian Agriculture Sector (million tons of CO_2 eq). (Source: INCCA, 2010)

– *Livestock:* Enteric fermentation in livestock constituted 63.4% of the total GHG emissions (CO_2 eq) from agriculture sector in India. The estimates cover all livestock, namely, cattle, buffalo, sheep, goats, poultry, donkeys, camels, horses and others. Manure management emitted 2.44 million tons of CO_2 eq.

– *Rice cultivation:* Rice cultivation emitted 69.87 million tons of CO_2-eq or 3.33 million tons of CH_4. The emissions cover all forms of water management practiced in the country for rice cultivation, namely, irrigated, rainfed, deep water and upland rice.

Agricultural soils and field Burning of crop residue: Agricultural soils are a source of N_2O, mainly due to application of nitrogenous fertilizers in the soils. Burning of crop residue leads to the emission of a number of gases and pollutants. Amongst them, CO_2 is considered to be C neutral, and therefore not included in the estimations. Only CH_4 and N_2O are considered for this report. The total CO_2-eq emitted from these two sources were 50.00 million tons.

Maheswarappa *et al*. (2011) reported that Indian agriculture in the beginning was with low C-based input of 69.7 Tg Ce/yr in 1960–61, input of fertilizers, pesticides, farm power, feed, fodder, and electricity has increased by about 4 times to 281.2 Tg Ce/yr by 2008–09. The output in agriculture increased about 2.14 times from 578.6 Tg Ce/yr in 1960–61 to 1239.1 Tg Ce/yr in 2008–09 (Fig. 5).

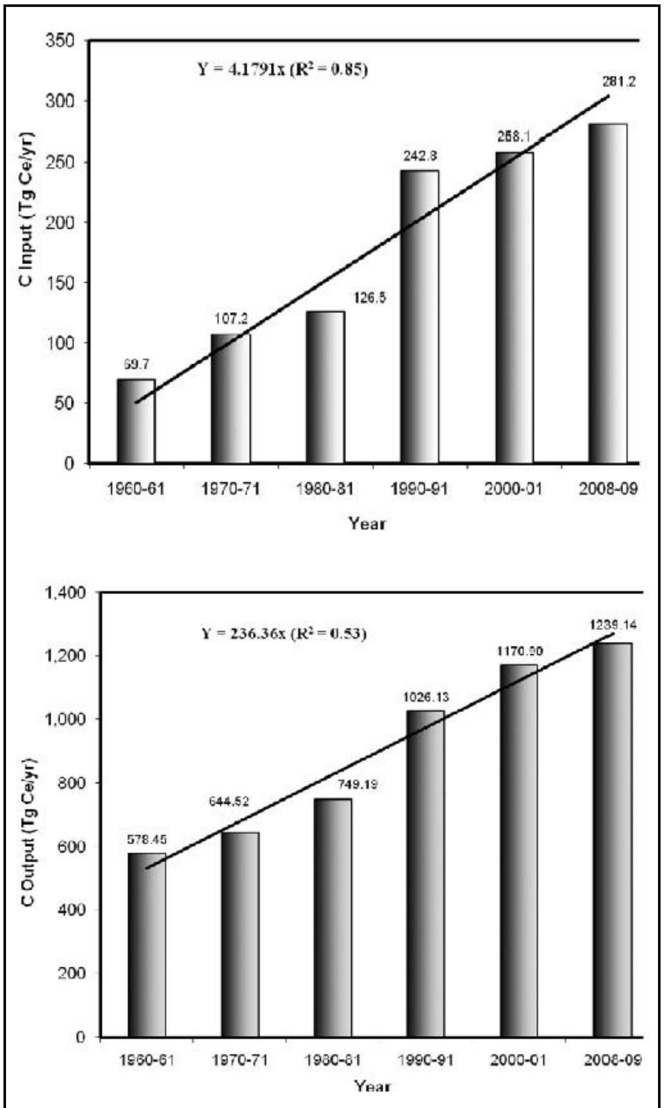

Fig. 5: Trends in C-based inputs and outputs in Indian agriculture since 1960

The quantum increase in C equivalent of inputs during the 1980s was mainly due to the increase in feed and fodder usages for increased milk production under the so called "White Revolution or operation flood," and to the adoption of intensive farming in Indo-Gangetic rice-wheat area compared to 1990s. Use of farm machinery has also increased since 2000. The C output-input ratio was 4.41 during 2008–09, compared with 8.30 in the pre-Green Revolution era and 5.9 in 1980–81(Table 1). An increase of 1 Tg/yr of C input resulted in a corresponding increase in C output of 20.6 Tg/yr. Despite an increase in use of fertilizers, the fertilizer-use efficiency decreased because of an imbalance in major nutrients. The C-sustainability index was high in 1960, and was indicative of the minimum usage of inputs prior to the onset of the Green Revolution. Thereafter, the C-sustainability index decreased during 1970s and 1980s because of increased C-based inputs (Fig. 6).

Table 1 : Total C input and output (Tg/yr) of Indian Agricultural Systems

Year	Total C input	Total C output
1960-61	69.7	578.5
1940-71	107.2	644.5
1980-81	126.5	749.2
1990-91	242.8	1026.1
2000-01	258.1	1170.9
2008-09	281.2	1239.1

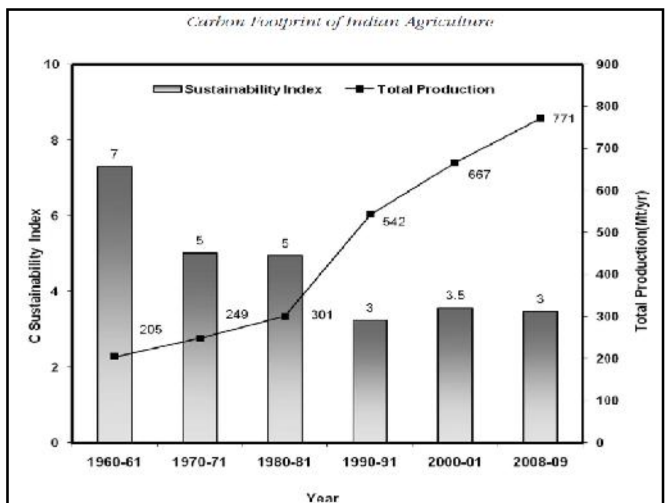

Fig. 6 : Trends in sustainability index and total production in Indian agriculture

Dubey *et al*. (2009) reported that the trend of C-based inputs in Punjab begins with low input of merely 0.04 Tg/yr in 1960, C-based input of fertilizer, pesticides, tillage, and irrigation increased to 1.57 Tg/yr by 2000, a 39-fold increase (Fig. 7). They also reported a linear relationship between C input and C output for Punjab, indicating that

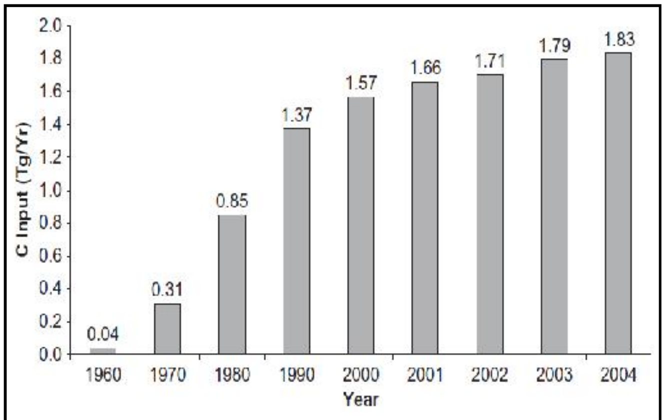

Fig. 7: Trends in C-based inputs in Punjab agriculture from 1960 to 2004

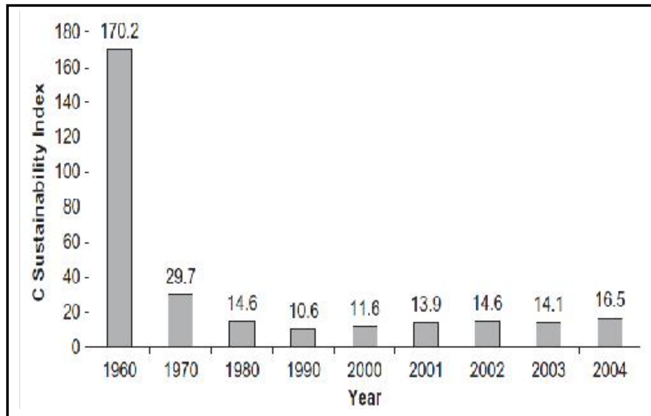

Fig. 9 : Trends in C sustainability index in Punjab agricultural ecosystem between 1960 and 2004

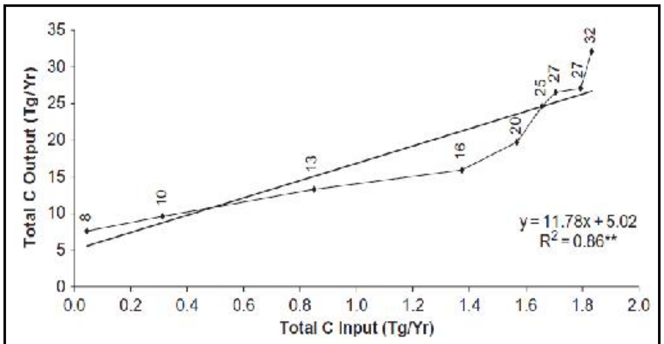

Fig. 8 : Relationship between total C input and C output in Punjab from 1960–2004
****indicates significance at P < 5%**

an increase of of C input resulted in the corresponding C output of ~12 Tg/yr.

In Punjab, crop residues are removed and in some cases burnt, resulting in loss of C from the soil organic carbon pool. The C-efficient systems are more sustainable than inefficient farming systems, and residue removal reduces agricultural sustainability by depleting the soil C pool.

Conclusion : Among several anthropogenic activities, agriculture is one of the major contributors of GHGs and among different GHGs it is the largest contributor of CH_4 and N_2O. Most of the present estimation of GHGs emission from agriculture is mainly based on direct emission from soil, livestock and burning of crop residues while a large quantity of CO_2 is also emitted from different stages of whole lifecycle *i.e.* from pre-farm, on-farm and post - farm activities. So characterizing the carbon footprint of agricultural production through LCA approach to get complete idea about the total GHGs emission from agriculture that can offer key information for pursuing low carbon agriculture and food consumption is going all over the world. Some of the Indian scientists have also calculated the carbon footprint of Indian agriculture. They reported that with time carbon footprint Indian agriculture has been increased and can be reduced by increasing the input use efficiency, following the conservation agriculture and changing the food consumption habit of people.

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