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Evaluation of Carbon Footprint of different Farm Operation: A Review

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Global climate change which is threatening the food security of developing countries is the biggest challenge to be addressed by the agriculture sector. Globally about one third of GHG emission is attributed to agriculture and land use change . At current rates of climate change average yields of major cereals such as; rice, wheat and maize are expected sto decrease INCCA (2010).The increasing populations on the other hand impose further pressure on food production under changing environments. Therefore agriculture is both cause and victim of climate change. To reduce emission levels from agriculture sector, the fundamental requirement is to quantify the carbon emission from various operations performed in a single whole cycle of crop production. As most agriculture practices are climate driven and therefore region and crop specific, it is necessary to quantify carbon emission at regional levels to address the global issue. 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).Mitigation practices need to be developed for individual agricultural systems in view of climate, and social setting, To do so, most fundamental requirement is to ascertain the carbon footprint of different crops and cropping systems and thereby bring in amendments to reduce the carbon foot print. Among the inputs used in the cultivation, most significant contributing factor seems to be puddling of rice, farm machinery, use of chemical fertilizers, irrigation practices etc. Fuel-use for various agricultural operations and burning of crop residues are the sources of carbon dioxide emissions. An off-site source of CO_2 is the manufacturing of fertilizers and pesticides. These emissions of GHGs also occur during production and consumption of food commodities. The opportunities for mitigating GHGs in agriculture centre around three basic principles: reducing emissions, enhancing sink or removals and avoiding or displacing emissions. Therefore, in order to reduce emission from agriculture sector amendments are needed for the current practices of cultivation like zero tillage, direct seeding of rice, drip irrigation, sprinkler irrigation, nutrient management etc. 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.

Keywords: Carbon foot print,CO_2,Farm Operation, India

1. INTRODUCTION

Today, global warming is the most prominent environmental issue before the humanity. It is caused by the increase in concentration of greenhouse gases (GHGs) in the atmosphere. The GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), trap the outgoing infrared radiations from the earth's surface and thus raise the temperature. The accumulation of GHGs in atmosphere and the consequent rise in earth's temperature is termed as 'greenhouse effect'. According to a world agency, Inter-Governmental Panel on Climate Change (IPCC), due to greenhouse effect the global mean annual temperature was recorded higher by 0.40-0.76°C at the end of the 20th century than was at the end of the 19th century (IPCC, 2007). This agency has projected a rise of 1.1 to 6.4°C in temperature by the end of the 21st century. The global warming is leading to several other regional and global changes such as shifting weather patterns, receding ice caps, crop losses, altered distribution of precipitation, increased frequency and intensities of floods and droughts rainfall. 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 burgeoning populations on the other hand impose further pressure on food production under changing environments. To feed these growing populations we need to increase the production as well as productivity without harming environment. Agriculture has the potential to mitigate emission of GHGs by adopting low carbon technologies, which make the agricultural operations economically and socially beneficial, and help protect the climate system for the present and future generations. Comprehensive estimates of GHGs emission from different agricultural operations including production, processing, post-harvest management and marketing are required for evaluating the economic potential of different low carbon technologies in Indian agriculture. Therefore, to reduce emission levels from agriculture sector, the fundamental requirement is to quantify the carbon emission from various operations performed in crop production. As most agriculture practices are climate driven and therefore region and crop specific, it is necessary to quantify carbon emission at regional levels to address the global issue. India is estimated to emit 17.6 % of its emission from agriculture sector, while it is 8 % in United States. Emission from agriculture depends on inputs used Cultivation practices adopted and soil fertility status. However, there are hardly any studies in developing countries to quantify the emission from cultivation process of agriculture of various crops and cropping systems. Mitigation practices need to be developed for individual agricultural systems in view of climate, edaphic, social setting, and historical patterns of land use and management. To do so, most fundamental requirement is to ascertain the carbon footprint of different crops and cropping systems and thereby bring in amendments to reduce the carbon foot print. Most tropical countries being highly diverse in climate, crops and therefore the cultivation practices, it is important to assess the carbon emission at regional levels to evolve appropriate strategies.

2.1 Carbon emission from farm operations

With reference to C emissions, agricultural practices may be grouped into primary, secondary and tertiary sources (Gifford, 1984). Primary sources of C emissions are either due to mobile operations (e.g., tillage, sowing, harvesting and transport) or stationary operations (e.g., pumping water, grain drying). 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.

2.2 Carbon emission from primary operations

2.2.1 Tillage

Tillage, defined as operations involving mechanical soil disturbance for seedbed preparation, affects emission directly and indirectly. Direct emissions are due to the fuel use for tillage, which depends on numerous factors including soil properties, tractor size, implement used and depth of tillage. The fuel requirement increases with increase in depth of ploughing and tractor speed (Collins *et al.*, 1976), and also differs among the type of equipment used. The direct fuel consumption is also more for heavy than light textured soils, and increases with increase in soil's cone index (Collins *et al.*, 1976).

Table 1: Equivalent carbon emission of different tillage operation

Tillage Operation	**Equivalent Carbon Emission**	
	Range	**Mean ± S.D.**
Moldboard Plowing	13.4-20.1	15.2 ± 4.1
Chisel Ploughing	4.5- 11.1	7.9 ± 2.3
Heavy Tandem disking	4.6 -11.2	8.3 ± 2.5
Standard tandem disking	4.0 -7.1	5.8 ± 1.7
Sub Soiler	8.5 -14.1	11.3 ± 2.8
Field Cultivation	3.0 -8.6	4.0 ± 1.9
Rotary hoeing	1.2 -2.9	2.0 ± 0.9

2.2.2 Irrigation

Irrigation is important to achieving high yields in arid and semi-arid regions. On a global scale, 17% of irrigated cropland leads to 40% of the total production (Postel, 1999). Yet, irrigation is a very C-intensive practice. Sloggett (1979; 1992) estimated that 23% of the on-farm energy use for crop production in the US was for on-farm pumping. The energy required to pump water depends on numerous factors including total dynamic head (based on water lift, pipe friction, and system pressure), the water flow rate and the pumping system efficiency (Whiffen, 1991). The energy use depends on the water table depth or the lift height.

Table 2: Installation energy of various irrigation systems

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System	Installation Energy (kg CE ha/year)
Surface without IRRS	9.4
Surface with IRRS	24.6
Solid set sprinkle	121.3
Permanent sprinkle	35.5
Hand moved sprinkle	16.3
Solid roll sprinkle	23.3
Center-pivot sprinkle	21.6
Traveler sprinkle	16.9
Trickle	84.9

2.2.3 Sowing, spraying, harvesting and transport

The data on kg CE/ha for harvesting, spraying, fertilizer application and other farm operations are presented in Table 3. Most C-intensive operations include harvesting corn for silage, forage harvesting, knife-down ammonia, combine harvesting corn and soybean, fertilizer spreading, planting potato and spreading/incorporating fertilizers or lime. Windrowing and baling hay are also C-intensive operations (Table 3). There is a strong need to enhance efficiency of these operations and reduce CO_2–C emissions.

Table 3: Equivalent carbon emission of various farm operations

Farm Operation	Equivalent carbon emission (kg CE/ha)	
	Range	Mean ± S.D.
Knife-down ammonia	10.1	10.1
Spray herbicide	0.7-2.2	1.4 ± 1.3
Plant/sow/drill	2.2-3.9	3.2 ± 0.8
No-till planting	3.7-3.9	3.8 ± 0.1
Chemical incorporation	3.6-7.8	5.7 ± 2.1
Fertilizer spraying	0.5-1.3	0.9 ± 0.4
Fertilizer spreading	5.1-10.1	7.6 ± 2.5
Potato planter	5.6-8.2	6.9 ± 1.3
Windrower	4.1-5.5	4.8 ± 0.7
Rake	1.0-2.4	1.7 ± 0.7
Baler (rectangle)	1-6-5.0	3.3 ± 1.7
Baler (large round)	2.8-8.8	5.8 ± 3.0
Corn silage	13.2-26.0	19.6 ± 6.4
Shred corn stalk	3.5-5.3	4.4 ± 0.9

Soybean harvesting combine	6.2-8.6	7.4 ± 1.2
Corn harvesting combine	8.5-11.5	10.0 ± 1.5
Forage harvesting	9.2-18.0	13.6 ± 4.4

2.3 Carbon emissions from secondary sources

2.3.1. Fertilizers

Use of nitrogenous fertilizer is a principal source of CO_2 and N_2O emissions. Therefore, enhancing fertilizer use efficiency and finding alternatives is important to reducing emission of GHG.

Table 4: Equivalent carbon emission of different type of fertilizers and pesticides

Fertilizers	**Equivalent carbon emission (kg CE/ha)**	
	Range	**Mean ± S.D.**
	Fertilizers	
Nitrogen	0.9-1.8	1.3 ± 0.3
Phosphorus	0.1-0.3	0.2 ± 0.06
Potassium	0.1-0.2	0.15 ± 0.06
Lime	0.03-0.23	0.16 ± 0.11
	Pesticides	
Herbicides	1.7-12.6	6.3 ± 2.7
Insecticides	1.2-8.1	5.1 ± 3.0
Fungicides	1.2-8.0	3.9 ± 2.2

2.3.2 Pesticides

Pesticides are also extremely C-intensive, and their use is increasing rapidly worldwide, but especially in India, China, Brazil and other emerging economies. Improper use can be a major environmental hazard and a principal source of pollution.

Table 5: Equivalent carbon emission of various types of fungicides and insecticides

Pesticide	**Equivalent carbon emission (kg CE/ha)**
Fungicides	
Ferbarn	12
Maneb	2.0
Capan	2.3

Benomyl	8.0
Insecticides	
Methyl paration	3.2
Phlorate	4.2
Carbofuran	9.1
Carbaryl	3.1
Taxaphene	1.2
Cypemermethrin	11.7
Chlorodimeform	5.0
Lindane	1.2
Malathion	4.6

Table 6: Equivalent carbon emission of various types of herbicides

Herbicides	**Equivalent carbon emission (kg CE/ha)**
2,4-D	1.7
2,4,5-T	2.7
Alachlor	5.6
Atrazine	3.8
Bentazon	8.7
Butlyate	2.8
Chloramben	3.4
Chlorsulfuron	7.3
Cyanazine	4.0
Dicamba	5.9
Dinoseb	1.6
Diquat	8.0
Metolachlor	5.5
Paraquat	9.2
Propachlor	5.8

3.1 Calculation of Carbon footprint

In soil, methane is formed from organic C present in soil and C added through organic residues, dead roots, and root exudates. Indigenous CH_4 emission (CH_4_em_ind, kg C $ha^{-1}d^{-1}$) was calculated as a function of available C substrate, that is, dissolved organic C, which in turn is related to soil organic carbon (SOC) (%), bulk density (g

cm^{-3}), soil depth (cm), crop duration (days), and the rate of decomposition (0.000085 per day) of SOC (Pathak and Wassmann, 2007):

Indigenous CH_4 emission

$$CH_4\_em\_ind = SOC \times 1000 \times \text{bulk density} \times \text{soil depth} \times 0.000085 \times \text{crop duration} \times 0.27 \times 0.55$$

Actual CH_4 emission (CH_4_em_ac, kg C ha^{-1} d^{-1}) was then calculated as

$$CH_4\_em\_ac = (CH_4\_em\_ind \times Tech\_CH_4 + (\text{root input} + \text{manure input} \times 0.5) \times 0.27 \times 0.55 \times 0.4) \times 2 \times (Temp - 25)/10$$

where, Tech_CH_4 is a technology-dependent factor for CH_4 emission; root input and manure input correspond to the respective organic input (kg); 0.5 represents the fraction of manure mineralized during the growing season (assuming that 50% of the manure will be decomposed during the fallow period); 0.27 is the ratio of the molecular weights of methane and carbohydrate; 0.55 is the initial fraction of produced methane that is emitted; 0.4 is the C content of the root and manure inputs; 2 × (Temp - 25)/10 is the temperature correction factor, where Temp is the seasonal average temperature (°C). Although manure inputs are documented for all technologies, root inputs (composed of exudates and dead roots) were derived from above-ground biomass using the equations derived by Pathak and Wassmann
(2007).

Nitrous oxide emission (N_2O_em_ac, kg N ha^{-1}) was related to the mineralization of organic N (from soil, residues, and manure) into an inorganic pool (NH_4^+), which was in turn related to the mineralization of C, addition of inorganic fertilizer as either NH_4^+ or urea forms, and rates of nitrification and denitrification (0.0024 kg kg^{-1}). A similar approach has been used in the denitrification and decomposition.

$$N_2O\_em\_ac = [(CO_2\_em\_ac + CH_4\_em\_ac)/10 + \text{Fertilizer N}] \times 0.0024 \times Tech\_N_2O$$

Tech_N_2O is the N_2O emission coefficient at different technology levels. (CO_2_em_ac, kg C ha^{-1}), that is, change in SOC, has been related to SOC (%) of soil, bulk density (g cm^{-3}), soil depth (cm), crop duration (days), rate of decomposition (0.000085 per day) of SOC, temperature correction factor.

$$CO_2\_em\_ac = SOC \times 1000 \times \text{bulk density} \times \text{soil depth} \times 0.000085 \times \text{crop duration} \times 2 \times (Temp - 25)/10 \times Tech\_SOC\_CO_2$$

Emissions of CO_2 from farm operations and for the production of various farm inputs were calculated using the values given by Pathak and Wassmann (2007). Global warming potential (GWP) is an index used to compare the effectiveness of each greenhouse gas in trapping heat in the atmosphere relative to a standard gas, by convention, CO_2. The GWP for CH_4 (based on a 100-year time horizon) is 25, while that for N_2O is 298 when the GWP value for CO_2 is taken as 1. Global warming potential (kg CO_2 equivalent ha^{-1}) of a system was calculated (IPCC, 2007) as:

GWP = CH_4_em_ac × 25 + N_2O _em_ac × 298 + (CO_2_em_ac)

$$CF_S = \sum_{i=1}^{3} [GWP\ (tier_i)]$$

$$CF_y = \frac{CF_S}{Grain\ yield}$$

4.1 Carbon footprint of rice and wheat system in indo-gangetic plain

The study was conducted for the upper-IGP and lower-IGP, the two predominantly wheat-consuming and rice-consuming regions of the country, respectively. The upper-IGP comprises Punjab, Haryana and western Uttar Pradesh, while eastern Uttar Pradesh, Bihar and West Bengal come under the lower-IGP. Emission of GHGs during the life-cycle of rice as well as of wheat in these two regions was calculated.

Table 7: Schematic diagram of different stages, processes, inputs, equipment and greenhouse gas emission in the life-cycle of rice production system

Stages	Process	Equipment	Input	GHG
Production	Tillage	Tractor/Power Tiller	Diesel	CO_2
		Bullock	-	CH_2
	Sowing	Seed drill	Diesel	CO_2
		Manual	-	-
	Transplanting	Manual	-	-
	Irrigation	Pump	Diesel/electricity	CO_2
	Fertilizer production	Factory	Electricity	CO_2
	Fertilizer application	Fertilizer drill	Diesel	CO_2
		Manual	-	-
	Biocide production	Factory	Electricity	CO_2
	Biocide application	Sprayer	-	-
	Soil microbial processes	-	-	CH_4 / N_2O / CO_2
	Harvesting	Combine	Diesel	CO_2
		Manual	-	-
Processing	Drying	Sun drying	-	-
		Machine dryer	Electricity	CO_2

	Milling	Stove	Biomass	CO_2/ CH_4 / N_2O
		Rice mill	Electricity	CO_2
Marketing	Packaging	Bag	Electricity	CO_2
	Transporting	Truck/Rail	Diesel/ Electricity	CO_2
	Storing	Warehouse	Electricity	CO_2
Consumption	Cooking	Oven	Gas/ Electricity	CO_2

Table 8: schematic diagram of different stages, processes, inputs, equipment and greenhouse gas emission in the life-cycle of wheat production system

Stages	**Process**	**Equipment**	**Input**	**GHG**
Production	Tillage	Tractor/Power Tiller	Diesel	CO_2
		Bullock	-	CH_4
	Sowing	Seed drill	Diesel	CO_2
		Manual	-	-
	Irrigation	Pump	Diesel/electricity	CO_2
	Fertilizer production	Factory	Electricity	CO_2
	Fertilizer application	Fertilizer drill	Diesel	CO_2
		Manual	-	-
	Biocide production	Factory	Electricity	CO_2
	Biocide application	Sprayer	-	-
	Harvesting	Combine	Diesel	CO_2
		Manual	-	-
Processing	Drying	Sun drying	-	-
	Milling	Mill	Biomass	CO_2/ CH_4 / N_2O
Marketing	Packaging	Bag	Electricity	CO_2
	Transporting	Truck/Rail	Diesel/ Electricity	CO_2
	Storing	Warehouse	Electricity	CO_2
Consumption	Cooking	Bakery	Gas/ Electricity	CO_2

Chapatti

4.2 Carbon footprint of rice and wheat

The GHG emissions and corresponding total global warming potential (GWP) of different processes in the life-cycle of rice and wheat are given in Tables 7 and 8, respectively. Total GWP of rice crop was relatively higher in the lower-IGP (1224 CO_2 eq.) than in the upper-IGP (931 CO_2 eq.). This was due to higher GWP of the rice production system; drying and parboiling post-production processes in the lower-IGP. Emissions during the production contributed more than 50% to the total GWP, followed by marketing (17 - 23%) in both the IGP regions. Among all post-production processes, parboiling of rice in the lower-IGP was the most energy intensive process having GWP of 198.4 CO_2 eq.

Table 9: Carbon footprint in the life-cycle of rice in the upper and lower Indo Gangetic Plains

Activity	Energy use MJ t^{-1}	CO_2-C kg t^{-1}	CH_4	N_2O-N	GWP
		Upper-IGP			
Production	-	54.7	11.2	0.26	602.3
Milling	92	2.3	-	-	8.4
Transportation (1000m)	-	13.6	-	-	50.0
Packaging	687	15.3	-	-	56.1
Marketing	2613	58.2	-	-	213.6
Total Carbon footprint					930.5
		Lower-IGP			
Production	-	26.7	19.6	0.13	649.2
Drying	976	24.4	-	-	89.5
Parboiling	2164	54.1	-	-	198.4
Steel huller milling	130	3.3	-	-	11.9
Transportation	-	1.4	-	-	5.0
Packaging	687	15.3	-	-	56.1
Marketing	2613	58.2	-	-	213.6
Total Carbon footprint			-	-	1223.7

Table 10: Carbon footprint in the life-cycle of wheat in the upper and lower Indo-Gangetic Plains

Activity	Energy use MJ t^{-1}	CO_2-C kg t^{-1}	CH_4	N_2O-N	GWP
		Upper-IGP			

Production	-	54.7	11.2	0.26	602.3
Production	-	67.0	-	0.19	335.8
Drying	976	24.4	-		89.5
Flour milling	105.3	2.6	-	-	9.7
Transportation	-	3.4	-	-	12.5
Packaging	687	15.3	-	-	56.1
Marketing	2613	58.2	-	-	213.6
Total Carbon footprint					717.1
Lower-IGP					
Production	-	51.67	-	0.14	253.4
Drying	976	24.4	-	-	89.5
Flour milling	68.5	1.7	-	-	6.3
Transportation	-	13.6	-	-	50.0
Packaging	687	15.3	-	-	56.1
Marketing	2613	58.2	-	-	213.6
Total Carbon footprint			-	-	668.9

4.3 Findings

- Methane emission is higher in lower IGP than higher IGP
- CO_2 emission is higher in higher IGP than lower IGP due to farm mechanization, irrigation and fertilizer consumption as well as crop burning
- Crop diversification has depicted reduction in carbon footprint ranged from 4.77% to 173.89% over the conventional management
- Zero tillage also has a high carbon footprint reduction strength of 83.9%
- Drip and sprinkler irrigation save irrigation water by 25-30% which saves energy
- Direct seeding of rice has carbon footprint reduction strength of 33.71%

4.4 Carbon footprint reduction

The opportunities for mitigating GHGs in agriculture centre around three basic principles: reducing emissions, enhancing sink or removals and avoiding or displacing emissions. Therefore, in order to reduce emission from agriculture sector amendments are needed for the current practices of cultivation like zero tillage, direct seeding of rice, drip irrigation, sprinkler irrigation, nutrient management etc

CONCLUSIONS

- To reduce GHGs emission from agriculture sector, there is need to quantify the carbon emission in terms of carbon footprint
- Fuel-use for various agricultural operations, puddling, and burning of crop residues are the sources of carbon. An off-site source of carbon is the manufacturing of fertilizers and pesticides.
- Proper farm implement selection for sustainable cultivation, Enhancing water use efficiency by adopting drip irrigation and sprinkle irrigation practices can save C emission
- No tillage system should be prefer in rice wheat cropping system, Direct seeding of rice and crop diversification also reduces the carbon footprint
- Therefore our aim should be to produce more with a low carbon footprint and less damage to the environment

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.

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