RESEARCH ARTICLE

EFFECT OF DIFFERENT RATE OF N APPLICATION ON MAIZE – WHEAT CROPPING SYSTEM IN RELATION TO GREENHOUSE GASES (GHGS) EMISSION

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Abstract: A field experiment was conducted to study the effect of different rate of nitrogen application on GHGs emission under maize-wheat cropping system in an acid soil. Nitrogen rates were arranged with four levels including (N_1: 0, N_2 : 80, N_3 : 160 and N_4 : 240 kg N ha^{-1}) in case of maize. However in case of wheat N rates was (N_1 = 0, N_2 = 50, N_3 =100 and N_4=150 kg N ha^{-1}). GHGs were estimated by using Cool Farm Tool (CFT), and the result showed that the application of higher dose of N, emitted more total GHGs (11163 kg CO_2eq ha^{-1} in maize and 7108 kg CO_2eq ha^{-1} in wheat, respectively. Similar trend was followed by emission of N_2O and CO_2. A breakdown of various emission sources shows that the major emission sources at farm level is the production and use of synthetic fertilizer. GHGs emission increased with increasing N application both maize and wheat crop and was observed highest at highest N application rate i.e. 240 kg N ha^{-1} and 150 kg N ha^{-1} (11163 and 7108 kg CO_2eq ha^{-1}, respectively) and lowest at no nitrogen applied plot (1941 and 2124 kg CO_2eq ha^{-1}) respectively.

Keywords: Carbon dioxide, Cool Farm Tool, Nitrogen fertilizer, Nitrous oxide, Maize-wheat

INTRODUCTION

GHGs emission is major concern over agriculture produce. The use of blanket nutrient management recommendations in India has led to low nutrient use efficiencies, lowered profits and increased environmental problems (Pampolino *et al*. 2012). Nutrient recommendations in India are based upon crop response data averaged over large geographic areas and do not take into account the spatial variability in indigenous nutrient supplying capacity of soils (Majumdar *et al*. 2013). Blanket nitrogen fertilizer application, therefore, results into under-fertilization in some cases and over-fertilization in other. Such unbalanced and inadequate use of nutrients can decrease the nutrient use efficiency and profitability and may increase environmental risks associated with loss of unutilized nutrient through emission or leaching. This further increases the agriculture's share to total GHGs emissions. Traditionally, maize is grown in the kharif season and wheat during *rabi* season. Farmers typically perform multiple tillage operations after wheat harvest to prepare field for maize and wheat planting. Increased use of machinery and fuel for repeated tillage operations also emits large amount of greenhouse gases (GHGs) into the atmosphereSapkota *et al*. (2014). Singh*et al.* (2014) it was reported in 2007 that the net emission of GHGs from India was 1727.7 MT of CO_2 equivalent. It has been shown that Punjab, Haryana, Uttar Pradesh and Andhra Pradesh emit higher amount of NO_2-N because of higher nitrogen fertilizer use. But West Bengal, Andhra Pradesh, Orissa, Bihar, Jharkhand and North-eastern States emit more amount of methane due to higher rice cultivation. Conservation agriculture holds key in reducing the emission due to minimum soil disturbance and 30% area covered with crop residue.

Gaseous exchange between soils and the atmosphere is an important contributory factor to global change due to increasing release of greenhouse gases (GHGs) (Smith *et al*. 2007). Nitrous oxide (N_2O) and carbon dioxide (CO_2) are the two most important greenhouse gases with important contributions to global warming (Wang *et al*. 2005) and agricultural soils act as the source of N_2O and CO_2 (Ding *et al*. 2006). It is estimated that about 20% of the global atmospheric source of N_2O is estimated to be related to emission from agricultural lands (Mosier *et al*. 1998), and about 25% of the total C exchange between the atmosphere and terrestrial sources is ascribed to annual global soil emission (Schlesinger and Andrews 2000). It is well known that N_2O and CO_2 production, transport and emission in soil depend on environmental factors such as aeration condition, soil temperature, soil moisture, supplies of organic carbon, fertilization, pH, etc. (Bowden *et al*. 2004; Lin *et al*. 2010).

Nitrogenous fertiliser can be responsible for the majority of greenhouse gas (GHG) emissions associated with the production of crops through its manufacture and N_2O emissions from the soil subsequent to its application. Emissions of N_2O that result from fertilizer N inputs to the soil can occur through both direct and indirect pathways. Direct emissions of N_2O are considered emissions from the soil that occur as a direct result of additional fertilizer N application to that same soil. Indirect emissions of N_2O are considered to be those produced off-site and

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include, but are not limited to, N_2O produced in receiving waters or soils as a result of NO_3^- ion leaching (Kindred *et al*. 2008).

However, carbon dioxide (CO_2), from energy use on farms and horticultural enterprises, accounts for only about 8% of these emissions. Most GHG emissions from agriculture are either nitrous oxide (N_2O; 57%), or methane (CH_4; 35%) - both important greenhouse gases that contribute to global warming and climate change. (FAS 2014)

Approximately 6-9% of all greenhouse gas (GHG) emissions originating in the United States (US) come from agriculture activities. In 2007, agriculture in US was responsible for around 7% of total GHG emissions, with soil management activities such as fertilizer N application accounting for almost 80% of total emissions of N_2O from this sector. The majority of N_2O emissions from agriculture in US are associated with field crop production. (CAST 2004; EPA 2009).These gases are in the forms of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). India is estimated to emit 17.6% of its emission from agriculture sector. However, by employing proper management techniques, agricultural lands can both sequester carbon and reduce CO_2, CH_4, and N_2O emissions, thereby reducing their GHG footprint (NCCA 2010).

MATERIAL AND METHOD

Experimental site

A field experiment was conducted at the research farm of Soil Science and Agricultural Chemistry, Birsa Agricultural University, Ranchi, during the year 2015-16 to study the effect of different rate of nitrogen application on GHGs emission under maize-wheat cropping system in an acid soil. The experiment was carried out on a sandy loam soil and comprising 12 treatments and 3 replications in a Randomized Block Design. Nitrogen rates were arranged with four levels including (N_1: 0, N_2 : 80, N_3 : 160 and N_4 : 240 kg N ha^{-1}) which was applied at different timing (S_1 : 1/3 after germination + 1/3 at V_4 stage + 1/3 V_{10} stage), (S_2 : 1/3 after germination + 1/3 in V_4 stage + 1/3 V_{10} stage may it be varied on leaf colour chart (LCC)), (S_3: ½ after germination + ½ in V_{10} stage) in case of maize. However in case of wheat N rates was (N_1 = 0, N_2 = 50, N_3 =100 and N_4=150 kg N ha^{-1}) consisting different timing schedule (S_1=1/3 after germination + 1/3 in crown root initiation stage (CRI) + 1/3 in PI), (S_2 + 1/3 after germination+ 1/3 in CRI + 1/3 in PI as per LCC), (S_3 = ½ after germination + ½ in CRI stage). Experimental plot is located in the Agro-climatic Zone V (situated at $23^0 19'$ north and $83^0 17'$) and has an altitude of 625 meter above MSL. The experimental area was well protected from all sides to prevent outside interferences and stray cattle. The area was divided into plots as per treatment for the conduct of field experiment. The soil of the experimental field was sandy loam in texture with low water and nutrient retention capacity. Soil taxonomy was Typic Paleustalf. The highest maximum average temperature was 29.2^0C and lowest minimum temperature was 17.2^0C during year 2015-16.

Weather Parameters during the crop season

The total rainfall received by the area during 2015-2016 maize-wheat crop growing season was 639 mm and the peak period of rainfall was June to September. During maize cropping season rainfall was about 522 mm and average temperature varied from 19.3^0C to 33.8^0C. While during wheat cropping season rainfall was about 47 mm and temperature varied from 3.1^0C to 39.5^0C.The highest average relative humidity was 87 percent at 7 AM in the 2^{nd} week of February to 1^{st} week of March 2016 and the lowest was 31 percent in 3^{rd} week of March at 2 PM.

GHG quantification (CO_2, N_2O)

Cool Farm Tool (CFT) model was used for estimation of GHGs.

Model: Cool Farm Tool (Hiller *et al*., 2011)

The Cool Farm Tool (Hillier *et al*., 2011), used in this study to estimate GHGs emission, integrates several globally determined empirical GHG quantification models in one tool. The tool recognizes context specific factors that influence GHG emissions such as: pedo-climatic characteristics, production inputs and other management practices at field as well as farm level. The model provides output as total emission of GHGs of interest both per unit area as well as per unit of product. This allows us to estimate the performance of production system from GHG emission perspective both in terms of land-use efficiency and efficiency per unit of product. The Cool Farm Tool is a farm-level greenhouse gas calculator for estimating net GHG emissions from agriculture field.

While harmonized with other calculators, this tool is distinguished by:

- Its farmer focus, being as management sensitive as possible while requiring only input data a farm manager would have typically.
- In IPCC terminology, its use of Tier II approaches – empirical models built from hundreds of peer-reviewed studies.

This calculator takes the estimates of technical potential to the farm and uncovers what is practical and pragmatic from a farmer and field perspective. The Cool Farm Tool sits between calculators using simple emission factor approaches (IPCC Tier 1); and those process based models which require a greater level of engagement on the part of the use and training to interpret (IPCC Tier 3).

The majority of calculators report the results in 'carbon dioxide equivalents' or CO_2eq.

This is to allow the impact of the gases to be directly compared. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) all have different global warming potential (GWP) – their potential to absorb and re-emit heat within the atmosphere, maintaining global temperature.

A kilogram of N_2O has the capacity to emit 310 times the amount of heat compared to 1 kg of CO_2 and is therefore equal to 310kg CO_2-eq. Methane has 21 times the GWP of CO_2, 1 kg is therefore equal to 21kg CO_2-eq.

1 kg CO_2 = 1 kg CO_2-eq

1 kg CH_4 = 21 kg CO_2-eq

1 kg N_2O = 310 kg CO_2-eq

(GWP defined by IPCC 2006)

Estimation of GHGs emission using CFT

The Cool Farm Tool was developed primarily by Jon Hillier at the University of Aberdeen and experts at Unilever and the sustainable food lab and it is available for free download and use under a creative commons license available from:

http://www.unilever.com/aboutus/supplier/sustainablesourcing/tools.

It is a Microsoft excel spreadsheet based tool designed to incorporate robust available science to help reverse engineer empirical data from global GHG calculation methods and data sets into a farm or field level GHG balance. The tool is farmer focused and captures on-farm activity data familiar to the farmer or that can easily be ascertained whilst in the field. (Keller*et al.*, 2011).

The calculator has seven input sections, each on a separate Excel worksheet, relating to:

- **General Information** (location, year, product, production area, climate)
- **Crop Management** (agricultural operations, crop protection, fertilizer use, residue-management)
- **Sequestration** (land use and management, above ground biomass)
- **Livestock** (feed choices, enteric fermentation, N excretion, manure management)
- **Field Energy Use** (irrigation, farm machinery, etc.)
- **Primary Processing** (factory, storage, etc.)
- **Transport** (road, rail, air, ship)

Through each of these sections and the results section to offer details and tips for accurately uses the Cool Farm Tool to calculate your farm's greenhouse gas emissions. Assessments cover both large scale production of crops including apples, tomatoes, potatoes, dairy, pulses, sugar and wheat along with a suit of small scale production suppliers of tea, coffee, beans and cotton. To ensure successful implementation into the diverse range of supply chains, the tool is accompanied by guidance documentation help text that has been integrated into the user interface.

RESULT AND DISCUSSION

Greenhouse gas (GHG) emission

Global warming, caused by the increase in the concentration of greenhouse gases (GHGs) in the atmosphere, had emerged as one of the most prominent global environmental issues. These GHGs – carbon dioxide (CO_2), methane (CH_4) and nitrous-oxide (N_2O), trap the outgoing infrared radiation from the earth's surface and thus raise the temperature. The global mean annual temperatures at the end of the 20^{th} century, as a result of GHG accumulation in the atmosphere, had increased by 0.4–0.76ºC above that recorded at the end of the 19^{th} century (IPCC, 2007).Agricultural soils contributed the greenhouse effect primarily through the emission and consumption of greenhouse gases (GHGs) such as methane, nitrous oxide and carbon dioxide.

Agriculture offers promising opportunities for mitigating GHG emissions through carbon sequestration, soil and land use management, and biomass production. For India's agricultural production systems to make viable into the future there is a need to identify soil management systems that are climate change compatible, where soil organic carbon is maintained or enhanced and GHG emission is reduced. The main aim of the assessment: To raise awareness, project evaluation or product assessment and policy formulation to encourage farmers for adopting the mitigation technologies without compromising production and income.

CO_2 Emission

Emission of carbon dioxide in maize field ranged from 1413 to 3078 kg CO_2 ha^{-1} while in wheat it varied from 1274 to 2314 kg CO_2 ha^{-1} depending upon different rate of N fertilizer (Table.1 and 2). On an average, maize production in 240 kg N ha^{-1} applied plot emitted 3078 kg CO_2 $ha^{-1}$and 160 kg N ha^{-1} applied plot emitted 2523 kg CO_2 ha^{-1} respectively. Minimum value recorded at 0 kg N level (1413 kg CO_2 ha^{-1}).

While observing data of wheat field highest value of CO_2 emission recorded at 150 kg N level (2314 kg CO_2 $ha^{-1)}$ followed by 100 kg N level (1967 kg CO_2 ha^{-1}). At 50 kg level (1620 kg CO_2 ha^{-1}) which was slightly higher than the lowest value (1274 kg CO_2 ha^{-1}) at 0 kg level (Table.2). The results are in conformity with the findings of Zhai Li-mei*et al.* (2011) reported similar results and indicated that GHGs emission increased with increasing N application.

The main source of carbon dioxide from agriculture is through soil management such as tillage which triggers carbon dioxide emission through biological decomposition of soil organic matter. Tillage breaks soil aggregates, increases oxygen supply and exposes surface area of organic material promoting the decomposition of organic matter. Fuel use for various agricultural operations and burning of crop residues are other sources of carbon dioxide emission. An off-site source is the production of carbon dioxide for manufacturing fertilizers and pesticides (Pathak *et al.*, 2010).

N_2O emission

Emissions of N_2O that result from fertilizer N inputs to the soil can occur through both direct and indirect pathways. Direct emissions of N_2O are considered emissions from the soil that occur as a direct result of additional fertilizer N application to that same soil (e.g., a producer's field within a defined boundary). Indirect emissions of N_2O are considered to be those produced off-site (beyond the boundary) and include, but are not limited to, N_2O produced in receiving waters or soils as a result of NO_3^- leaching (IPCC 2006).

Nutrient management strategies had significant effect on estimated N_2O emission per hectare as well as per tonne of crop yield. In both crop (Maize – Wheat) different rate of N application had significant effect on estimation of N_2O emission per hectare within treatment.In case of maize estimated N_2O emission was higher in 160 kg N ha^{-1} applied plot (11.3 kg N_2O ha^{-1}) than 80 kg N ha^{-1} applied plot (4.7 kg N_2O ha^{-1}). But estimated N_2O emission was the highest (27.3 kg N_2O ha^{-1}) under highest N (240 kg N ha^{-1}) and lowest with application of 0 kg N ha^{-1} (1.8 kg ha^{-1}) (Table.1). The results of this investigation are in consonance with the findings of Daripa *et al.* (2014) and Zheng *et al.* (2016).Estimated emission per tonne of maize yield was not followed the same trend like as emission per hectare. It is due to the reason that it was related to yield of crop but per hectare value depend on yield, fertilizer doses and other parameters which were involved on crop production.

While the estimated N_2O emission on the basis of per tonne of maize yield was lowest under 80 kg N application plot (1.17 kg $tonne^{-1}$) and highest value found in 240 kg ha^{-1} applied plot (3.59 kg $tonne^{-1}$) which is followed by 0 kg N ha^{-1}applied plot (3.15 kg $tonne^{-1}$). The value of estimated N_2O emission per tonne was slightly higher in 160 kg N ha^{-1} applied plot (1.57 kg $tonne^{-1}$) than 80 kg N ha^{-1} applied plot (1.17 kg $tonne^{-1}$) (Table.1).This is confirmed that N input gradients in row-crop agriculture had found that emissions of N_2O correlate well with fertilizer N rate (Mosier *et al*. 2006; Halvorson *et al.* 2008; Hoben *et al.* 2010, *Millar et al*. 2010). In all of these studies, increasing the amount of N added to soil resulted in increasing emissions of N_2O. This is the foundation for current IPCC (2006) greenhouse gas inventory calculations. It was due to interaction of many factors such as soil temperature, soil structure, water-filled pore space and soil organic matter influence N_2O emission from soil. In general, fertilizer application and residue management are two major factors contributing to N_2O emission in agro-ecosystem (Rochette *et al*., 2008). In case of wheat estimated value of N_2O emission per hectare during rabi season was higher in 100 kg N ha^{-1} applied plot (9.2 kg N_2O ha^{-1}) than 50 kg N ha^{-1}applied plot (5.2 kg ha^{-1}). Estimated N_2O emission was the highest (16.2 kg ha^{-1}) with application of150 kg N ha^{-1} applied plot and lowest under 0 kg N ha^{-1} (2.9 kg ha^{-1}) (Table. 2). Where, as estimated N_2O emission per tonne on the basis of wheat yield was lowest in 50 kg N treated plot (1.85 kg $tonne^{-1}$) and highest value of N_2O was found with application of 150 kg N ha^{-1} (3.6 kg $tonne^{-1}$)which is followed by 0 kg N ha^{-1} applied plot (3.2 kg $tonne^{-1}$). Estimated N_2O emission per tonne was higher in 100 kg N ha^{-1} applied plot (2.24 kg $tonne^{-1}$) than 50 kg N ha^{-1} (1.85 kg $tonne^{-1}$) (Table.2). The variation of NO_2 emission per tonne (basis of yield) was observed due to yield variation. Similar results were report by Rajaniemi *et al.* (2011).

Methane emission

Using CFT model, no methane gas emission value was found as crop residues were removed off the field before sowing of maize and wheat. Production of CH_4 in soil is dependent on limited O_2 supply which was controlled by soil water content. As wheat was grown during cold and dry winter, less water content in soil might be one of the major reasons for non-emission of CH_4 (Pathak *et al.*, 2010).

Total GHG emission

Maize

Estimated total GHG emission i.e. global warming potential (GWP) per hectare as well as per tonne of crop yield in terms of CO_2equivalent (CO_2-eq) was significantly different among different rate of N application (Table.1&2).Result showed that the magnitude of total GHGs emission in maize production varied from 1941 to 11163 kg CO_2-eq ha^{-1} with application of 0 kg N ha^{-1} and 240 kg N ha^{-1} applied plots, respectively. Emission was increased with increasing rate of N fertilizer. Highest emission of GHGs was resulted with application of 240 kg N ha^{-1} which was followed by 160 kg N ha^{-1} (5880 kg CO_2-eq ha^{-1}) and minimum emission observed with application of 0 kg N ha^{-1} (1941 kg CO_2-eq ha^{-1}). While in 80 kg N ha^{-1} applied plot emission was 3350 kg CO_2-eq ha^{-1} which was slightly lower than 160 kg N ha^{-1} applied plot. The magnitude of N_2O emissions during the crop growth period was mostly influenced by the availability of mineral N.

The value of total estimated GHG emission in terms of CO_2-eq per tonne of product was significantly higher under control condition than other plots. On average, maize emitted 3358, 834, 819, 1468 kg CO_2-eq $tonne^{-1}$ by 0, 80, 160, 240 kg N ha^{-1} applied plot respectively.

Wheat

Total estimated GHGs emission per ha and per tonne of wheat yield followed the same trend like maize but magnitude was less. Highest emission of GHGs per ha observed in 150 kg N ha^{-1} treated plot (7108 kg CO_2-eq ha^{-1}) followed by 100 kg N ha^{-1} applied plot (4702 kg CO_2-eq ha^{-1}) and minimum in 0 kg N ha^{-1} applied plot (2124 kg CO_2-eq ha^{-1})(table. 2). The value of total estimated GHG emission in terms of CO_2-eq per tonne of product was minimum in 100 kg N ha^{-1} applied plot (1120 kg CO_2-eq $tonne^{-1}$) and highest in 0 kg N ha^{-1} applied plot(2349 kg CO_2-eq $tonne^{-1}$) because of variation in yield of wheat, Slight difference of total GHGs emission was found between 100 kg N ha^{-1} applied plot (1120 kg CO_2-eq $tonne^{-1}$)and 50 kg N ha^{-1} applied plot (1124 kg CO_2-eq $tonne^{-1}$) while higher value was recorded in 150 kg N ha^{-1} applied plot (1545 kg CO_2-eq $tonne^{-1}$).

The value which was obtained by using CFT was depends upon yield, biological produce and rate of N application. Results revealed that using a higher amount of input, the overall emission was low as compared to the addition of lower amount of inputs. A breakdown of the various emission sources showed that (Table. 3& 4) the major emission source at farm level was the production and use of synthetic fertilizers. Similar results were report byGhahderijani *et al.* (2013).Fertilizer production and nitrous oxide emissions account for about 32 and 67% of the total on farm emissions respectively, in contrast to this, pesticides account only 0.5% in maize. While in wheat about 35 and 64 % emission from fertilizer production and nitrous oxide emission and about 0.6 % from pesticides. GHGs emissions though use of nitrogenous fertilizer were divided into induced nitrous oxide emissions and emissions of GHGs occurring from the production of these fertilizers. Nitrous oxide emissions occur from microbial processes in soils. The process of oxidation of ammonium to nitrates and reduction of nitrate to gaseous forms of nitrogen are the sources of N_2O emissions in agriculture (Granli and Bockman, 1994). N_2O emissions from soils are the dominant sources of atmospheric N_2O, contributing to about 57% of the total annual global GHG emissions (IPCC, 2006). GHG emissions from the production of fertilizers are the result of industrial processes such as ammonia production, phosphoric acid production and nitric acid production (Kongshaug, G., 1998).

Table 1. Effect of different rate of N application on GHGs emission in maize

Nitrogen Rate (kg ha^{-1})	CO_2 (kg ha^{-1})	CH_4 (kg ha^{-1})	N_2O		Total emission	
			(kg ha^{-1})	(kg $tonne^{-1}$)	(kg CO_2eq ha^{-1})	(kg CO_2eq $tonne^{-1}$)
N1 (0 kg N)	1413	0	1.8	3.15	1941	3358
N2 (80 kg N)	1968	0	4.7	1.17	3350	834
N3 (160 kg N)	2523	0	11.3	1.57	5880	819
N4 (240 kg N)	3078	0	27.3	3.59	11163	1468

Table 2. Effect of different rate of N application on GHGs emission in wheat

Nitrogen Rate (kg ha^{-1})	CO_2 (kg ha^{-1})	CH_4 (kg ha^{-1})	N_2O		Total emission	
			(kg ha^{-1})	(kg $tonne^{-1}$)	(kg CO_2eq ha^{-1})	(kg CO_2eq $tonne^{-1}$)
N1 (0 kg N)	1274	0	2.9	3.2	2124	2349
N2 (50 kg N)	1620	0	5.2	1.85	3166	1124
N3 (100 kg N)	1967	0	9.2	2.24	4702	1120
N4 (150 kg N)	2314	0	16.2	3.6	7108	1545

Table 3. Effect of different rate of N application on GHGs emission (kg ha^{-1}) from different sources of farm in maize

Nitrogen Rate (kg ha^{-1})	Fertilizer production (kg $ha^{-1)}$	Direct and indirect N_2O (kg $ha^{-1)}$	Pesticides (kg $ha^{-1)}$
N1(0 kg N)	1392	528	21
N2(80 kg N)	1669	1661	21
N3(160 kg N)	1946	3914	21
N4(240 kg N)	2223	8920	21

Table 4. Effect of different rate of N application on GHGs emission (kg ha^{-1}) from different sources of farm in wheat

Nitrogen Rate (kg ha^{-1})	Fertilizer production (kg $ha^{-1)}$	Direct and indirect N_20 (kg $ha^{-1)}$	Pesticides (kg $ha^{-1)}$
N1(0 kg N)	1253	850	20.5
N2(50 kg N)	1426	1720	20.5
N3(100 kg N)	1599	3083	20.5
N4(150 kg N)	1772	5316	20.5

CONCLUSION

This study usedMicrosoft excel spreadsheet based tool CFT to calculate GHG emissions from field crops. Application of synthetic fertilizer to the soil results in the highest GHG emissions. GHGs emission increased with increasing N application both maize and wheat crop and was observed highest at highest N application rate i.e. 240 kg N $ha^{-1}$and 150 kg N ha^{-1} (11163 and 7108 kg CO_2eq ha^{-1}, respectively) and lowest at no nitrogen applied plot (1941 and 2124 kg CO_2eq ha^{-1}) respectively.

Cereal crops are responsible for 68% of the national total emissions with maize contributing to 56% of the national total. Production of maize and wheat results in highest commodity GHG emissions in the country. Tonnes of CO_2-eq ha^{-1} are highest for vegetables and lowest for cereals. This study improves knowledge about GHG emissions from crop production that is necessary to guide national mitigation plans in the agriculture sector. It has reduced uncertainties regarding contributions of each field crop commodity to the emissions of the sector. CFT is a good tool to compile agricultural GHG inventories and to archive the information. However, it requires extensive activity data which may be expensive to collect and synthesise depending on the national circumstances. Regular updating of the field crop emission profiles is needed and affordable mechanisms to collect information from the farmers must be developed. This can be achieved by establishing sustainable institutional arrangements with specific mandates. Collaboration between relevant institutions needs to be improved, especially with regard to data sharing.

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