Research Paper

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Carbon footprint for wheat and corn under Egyptian conditions

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Abstract

Egyptian agriculture faces the challenge of ensuring food security while mitigating greenhouse gas emissions under climate change. Using life-cycle analysis to characterize the carbon footprint of crop production is critical to identify key measures which mitigate greenhouse gas emissions while sustaining crop productivity in the near future. Agriculture contributes a significant share of greenhouse gas emissions and concurrently represents a carbon dioxide (CO_2) sink, and thus, it has two fold opposing impacts on climate change. The carbon footprint of agricultural products is one of main measures for monitoring the efficiency and sustainability of agricultural productivity processes. Studies on the sustainability of crop production systems should consider both the footprint and the crop yield. In this study, 10-years of wheat and corn cultivated areas and yields were examined/analyzed from the statistics of the Ministry of Agriculture and Land Reclamation. To estimate greenhouse gas emissions, Egypt is divided into four regions; Delta, Middle, Upper Egypt, and lands outside the Nile Valley. The greenhouse gas emissions for both crops were estimated from different sources, including Nitrous oxide N_2O (synthetic fertilizers, manure fertilizer and crop residues) and carbon dioxide from fuel consumption (operation machinery and water pump). The results indicated that synthetic fertilizer had the highest greenhouse gas emissions at 47.2 and 45.5% for wheat and corn, respectively. Furthermore, the manure fertilizer presented the second source of greenhouse gas emissions with values of 35.4 and 33%. The lowest emissions were released from the fuel consumption (4.4 and 4.8%) for wheat and corn, respectively. The carbon footprint for wheat was 0.239 and 0.307 kg CO_2eq /kg grain yield for corn.

Introduction

Maize and wheat are cultivated in all agro-climatic zones (Delta, Middle, and Upper Egypt) in Egypt from North to South. The cultivated area of maize in 2017 was 794,704 hectares with an average productivity equal to 8.1 t/ha . The cultivated area of wheat was 1,257,277 hectares with average productivity of 6.5 t/ha in 2017.The agriculture and livestock sectors are large contributors of nitrous oxide (N_2O) and methane (CH_4) emissions in countries with agricultural activities. Such remedial measures are needed in these sectors to curb contributions to global warming (Kanyama and González, 2007). The particular in areas where the global warming potential that is related to agricultural activities is relatively high (e.g. nitrous oxide emission from the soil and manure storage, methane emissions from manure storage and enteric fermentation). This includes areas where about 13% of the annual global warming potential is related to all human activities (Olivier et al., 2005). Greenhouse gas emissions contribute to global warming by about 7% by converting natural habitats

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into permanent agriculture. The anthropogenic greenhouse gas emissions contribute to soil organic carbon decay and peat oxidation by approximately 10% (based on IPCC, 2007; FAO, 2001).

Sustainability of agricultural systems depends on their carbon (C) footprint, and the C_{output} :C_{input} ratio. The carbon footprint of agricultural products is one of main indicators for monitoring the efficiency and sustainability of agricultural productivity processes. Greenhouse gas emissions are one of the key indicators in assessing the environmental sustainability of farming. In order to quantify the impacts we define and use the term "carbon footprint". These are the most commonly used terms in the full "Life-Cycle-Assessment" (i.e., LCA) analysis for quantifying the impact of farming activity on the environment. (Gómez-Limón and Sanchez-Fernandez, 2010). However, product carbon footprinting currently faces some major drawbacks that drive some experts to see CFP as a "wasteful distraction" and that it would be better to devote management time and resources to other decarburization initiatives (McKinnon, 2010).

The Life Cycle Assessment (LCA) was recognized as an appropriate tool to estimate the climate impact or carbon footprint of crop production (Hillier et al., 2009). Therefore, the carbon footprint has been defined as "a measure of the exclusive total amount of carbon dioxide emissions that was directly and indirectly caused by an activity or was accumulated over the life stages of a product" (Wiedmann and Minx, 2008). The life cycle of wheat included production, transportation, use of machinery use and manufacture released GHGs through burning of fossil fuel during field operations, and the manufacture of farm equipment (e.g. tractors). All on-farm operations, including application of pesticides and fertilizers, were integrated into this LCA (Ho, 2011).

The agricultural sector is vital to sustainable human existence, therefore, we cannot ignore the real and substantial role that agriculture plays in GHG emissions nor the potentially catastrophic effects on food security and sustainability if planning for the sector does not consider climate change (Moreau et al., 2012). The carbon footprint and assessment standard is one of the most basic and crucial research in low-carbon research. However, due to this issue consistent results have not been achieved yet, and hence, concerned research were greatly affected. Research on the carbon footprint and assessment standards has become a hot topic for governments and researchers. More importantly, to make general public is becoming more aware and concerned about the effect of farming on environmental sustainability and society health as a whole. This paper describes the structure of the model calculation of the carbon footprint of agricultural products (wheat and corn) and the establishment of a database for Egypt. The results present an assessment of the carbon footprint of grains (wheat and corn) by using farming data at different agro-climate zones in Egypt.

Methodology

Study area

This study focuses on the cultivated areas for wheat and corn in Egypt. Statistics were collected from the Ministry of Agriculture and Land Reclamation from the years 2006 to 2015. Greenhouse gas emissions were calculated in four regions: Delta, Middle, and Upper Egypt, and lands outside the Nile Valley as shown in Figure (1). Egypt has been divided into several agro-climatic regions according to the average temperature values. The most important agro-climatic regions are: the Delta region (30°N – 31°N), represented by seven governorates (Kafr El-shiekh, Dakahlia, Sharqia, Ismailia, Portsaid, Suez and Cairo); the Middle Egypt region (28°N – 30°N), represented by four governorates (Giza, Fayoum, Beni Suif and Menya) and the Upper Egypt region (24°N – 28°N) represented by five governorates (Asyut, Sohag, Qena, Luxor and Aswan) (Abdrabbo et al., 2015). Table (1) demonstrates the average cultivated area, production and yield for wheat and corn in four regions over ten years.

IPCC (2006) suggests different approaches to calculate emissions. These approaches are called Tier 1, Tier 2 and Tier 3, with increasing levels of detail and complexity. Tier 1 is suitable for cases in which either no detailed data are available or global results are sought, though significant variations, such as climate, region, type of harvest and animal rearing, irrigation procedure, soil and manure management are considered. In this approach, agronomy data from global databases can be used (for instance FAO data). Under Egyptian conditions, Tier 1 is suitable to calculate emissions.

Nitrous oxide (N2O) from synthetic fertilizers applied on soils

The application of nitrogen fertilizer increases the probability of nitrous oxide N_2O emitted from microbial activity in soils. However, a fraction of direct volatilization as ammonia and nitrogen oxide must be subtracted as the microbes in the soil do not use this. Then, the amount of nitrous oxide N_2O emitted from the application of nitrogen fertilizers is given by the following equation (1) according to (IPCC 2006):

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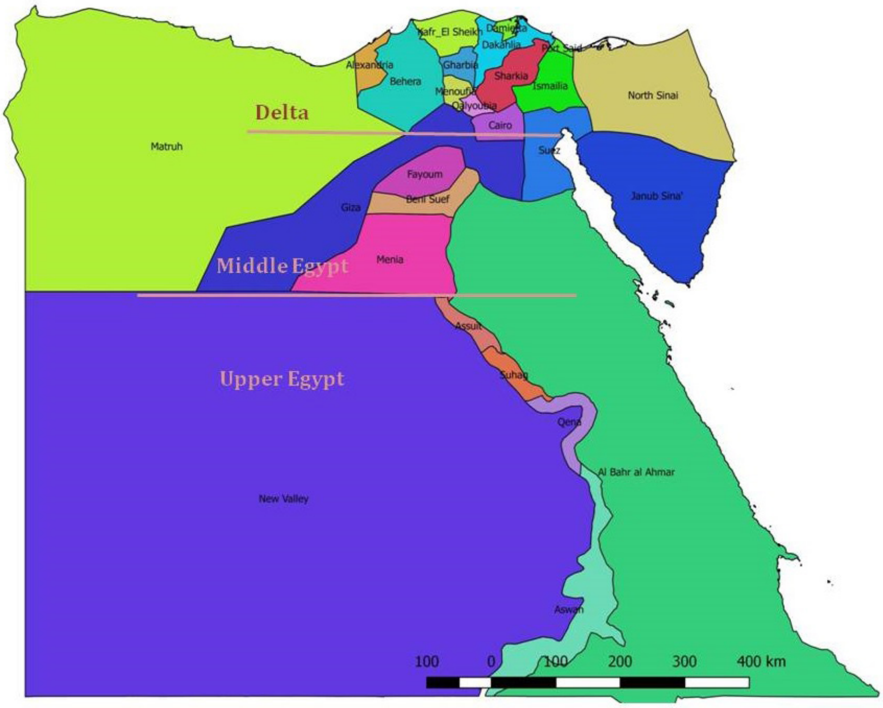

Figure 1: Different Egyptian regions; Delta, Middle, and Upper Egypt and lands outside the Nile Valley (Source: GIS unit, Central Laboratory for Agricultural climate, Agriculture Research Center)

$$N_2O_{fertil} = M_{fertile} * (1- fr_{atm,\,f}) * \varepsilon_{\ factor} * (M_{N_2O} / M_{N_2}) * GWP_{N_2O} \qquad (1)$$

Where

M_{fertil} = mass of nitrogen in fertilizer needed to produce the amount of product analyzed (kg N applied/ kg product analyzed)

$fr_{atm'f}$ = fraction of nitrogen that is released into the atmosphere as NH3 or NOx, (from Table 11.3, Chapter 11 of (IPCC, 2006)

$\varepsilon_{\ factor}$ = emission factor for fertilizer, i.e. kg of N2O-N per kg N applied (from Table 11.1 chapter 11 of IPCC, 2006

M_{N_2O} / M_{N_2} = 44/28 is the mass ratio of nitrous oxide N_2O and N_2

$GWPN_2O$ = Greenhouse Warming Potential of N_2O with respect to CO_2

Nitrous oxide (N2O) from application of manure on soils

The amount of N_2O emitted from application of manure fertilizer on soils is given by the following equation (2) according to (IPCC 2006):

$$N_2O_{m,\,fertil} = M_{manure} * (1- fr_{atm,m}) * \varepsilon_{factor} * (M_{N_2O} / M_{N_2}) * GWP_{N_2O} * N_{manure} \qquad (2)$$

Where:

M_{manure} = mass of manure needed to produce the amount of product analyzed (kg manure per kg product analyzed)

$fr_{atm'\ m}$ = fraction of nitrogen from manure applied that is released into the atmosphere as NH or NOx (from Table 11.3, Chapter 11 of IPCC, 2006)

$\varepsilon_{\ factor}$ = emission factor for converting nitrogen, i.e. kg of N2O-N per kg N applied

M_{N_2O}/M_{N_2}= 44/28 is the mass ratio of N_2O and N_2 $GWPN_2O$ = Greenhouse Warming Potential of N2O with respect to CO_2

N_{manure}= fraction of nitrogen per unit of manure (kg N/ kg manure)

Nitrous oxide (N_2O) from crop residues applied on soils

These emissions are released from the additional nitrogen when crop residues are left on soils. Since no-till techniques are becoming common practice in modern agriculture, their contribution might be significant. The calculation for emissions in residues is based on the estimate of N left in the dry matter of the above-ground (AG) and belowground (BG) crop residues. The mass of N in residues per year and hectare, $M_{N,residue}$, is given by the following equation (3) according to (IPCC 2006):

$$M_{N,residue} = Y_{fresh} * f_{\ dm} * [R_{AG} * N_{AG} + R_{BG} * N_{BG}] \qquad (3)$$

Table 1: The cultivated area, production and yield for wheat and corn in four regions

Cities	Area (ha)	Product (ton)	Yield (ton/ha)
Wheat			
Delta	700,651	4,812,280	6.9
Middle Egypt	226,689	1,576,791	7.0
Upper Egypt	221,011	1,451,801	6.6
Outside valley	108,925	610,128	5.6
Egypt	1,257,277	8,450,999	6.5
Corn			
Delta	391,295	3,447,527	8.8
Middle Egypt	228,869	1,774,365	7.8
Upper Egypt	146,279	1,092,874	7.5
Outside valley	28,261	240,321	8.5
Egypt	794,704	6,555,088	8.1

Where:

Y_{fresh} = yield for crop in fresh weight (kg crop / ha)

f_{dm} = fraction of dry matter (DM) in crop

R_{AG} = ratio of above-ground DM residues to harvested crop DM.

N_{AG} = N content of above-ground residues (kg N/ kg DM)

R_{BG} = ratio of below-ground DM residues to harvested crop DM

N_{BG} = N content of below-ground residues (kg N/ kg DM)

Data for all factors is shown in Table 2. Once the application of the emission intensity estimates the content of N in residues is obtained by multiplying by the corresponding mass and GWP factors.

$$N_2O_{N,\, residue} = M_{N,residue} * \varepsilon_{factor} * (M_{N_2O}/ M_{N_2}) * GWP_{N_2O} * M_{crop} / Y_{fresh} \qquad (4)$$

Where:

ε_{factor} = emission factor for converting nitrogen into N_2O (equal to 0.01 kg of N_2O-N/ kg N, from Table 11.1 Chapter 11 of IPCC, 2006)

M_{N_2O} / M_{N_2}= 44/28 is the mass ratio of N_2O and N_2

GWP_{N_2O} = Greenhouse Warming Potential of N_2O with respect to CO_2

M_{crop} = fraction of product analyzed per unit of crop harvested (kg crop/ kg product analyzed)

Emission from fuel consumption

Power requirements and fuel used per hectare for specific farming tasks are shown in Table 3 (Grisso et al., 2014). Assumed typical conditions and average working depths may be used to make fuel estimates for the indicated operations. Predicting fuel consumption for a specific operation can be estimated using the following calculation according to ASABE Standards (2006, 2009). The equation has been used widely for estimating fuel consumption (5):

$$Q_{avg} = 0.305 \times P_{Ene} \qquad (5)$$

Where

Q_{avg} = average diesel fuel consumption, L/h

P_{Ene} = maximum Engine power, kW

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Table 2: The factors for equation of Nitrous oxide (N2O) from crop residues applied on soils

	f_{dm}	N_{AG}	R_{BG}	N_{BG}
Corn	0.87	0.006	0.22	0.007
Wheat	0.89	0.006	0.23	0.009

*source Chapter 11(table 11.2): N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application (IPCC, 2006)

Table 3: Average energy-use rates and fuel requirements for farming tasks

Operation	Farm energy audita	L/ha
	Average from (gal/ac)	
Primary tillage		
Chisel disk	1.1	10.45
harvesting		
Mower	0.5	4.75
Small grain or bean combine	1.51	14.345
Thresher	1.4	13.3
Water pump	1.5	14.3

Source: Helsel, Z., and T. Orguntunde 1958. Fuel requirements for field operations with energy saving tips. InFarmEnergy Use: Standards, Worksheets, Conservation, ed. C. Myers. East Lansing: Michigan State University.blowa, Pennsylvania, Nebraska, Missouri, New York, Oklahoma, North Dakota, and Ontario, Canada.

$$Q = (0.22\,X + 0.096) \times P_{Ene} \qquad (6)$$

Where
Q = diesel fuel consumption at partial load, L/h

X = the ratio of equivalent Engine power to rated Engine power, decimal

P_{Ene} = the rated Engine power, kW

Power requirements for thresher and mower:

The following equation (7) is used to estimate ending used engine power (EP) according to Donnell (1983).

$$EP = [f.c(1/3600)\ PE \times L.C.V \times 427 \times \eta thb \times \eta m \times 1/75 \times 1/1.36] \qquad (7)$$

Where
$f.c$ = The fuel consumption, (L/h)

PE = The density of fuel, (kg/L) (0.823 kg/L)

$L.C.V$ = the lower calorific value of fuel, (11000 k.cal/kg)

ηthb = Thermal efficiency of the engine, (35% for Diesel)

427 = Thermo-mechanical equivalent, (kg.m/ k.cal)

ηm = Mechanical efficiency of the engine, (80% for Diesel)

Footprint Calculation

Global warming potential (GWP) of all the tiers is calculated individually using the conversion factors of IPCC (2007) corresponding to a 100-year time horizon. The formula for the calculation of GWP of tier$_i$ (i = 1, 2 or 3) is given by equation (8):

$$GWP(tier_i) = \text{emission/removal of } CH_4 \times 25 + \text{emission/removal of } N_2O \times 298 + \text{emission/ removal of } CO_2 \qquad (8)$$

Table 4: Emissions of N_2O and CO_2 from synthetic fertilizers applied on soils for wheat and corn crops

Region	Product (ton)	kg N_2O/ ton harvest	kg CO_2/ ton harvest	ton CO_2eq
Wheat				
Delta	4,812,280	0.38	112.4	540,845
Middle Egypt	1,576,791	0.38	112.4	177,213
Upper Egypt	1,451,801	0.38	112.4	163,166
Outside valley	610,128	0.38	112.4	68,571
Egypt	8,450,999	0.38	112.4	949,796
Corn				
Delta	3,447,527	0.48	144.5	498,166
Middle Egypt	1,774,365	0.48	144.5	256,395
Upper Egypt	1,092,874	0.48	144.5	157,920
Outside valley	240,321	0.48	144.5	34,726
Egypt	6,555,088	0.48	144.5	947,207

Where, GWP is in kg CO_2-e ha^{-1}. Emissions are taken as positive while removal as negative. Values are given in kg ha^{-1}. Carbon footprint is calculated by adding the GWP of all tiers. The final representation of the carbon footprint of agricultural systems can be made as spatial or yield scaled carbon footprints according to the formulae are given below equation (9 &10):

$$CF_s = \sum_{i=1}^{3}[GWP(tier_i)] \qquad (9)$$

$$CF_y = \frac{CF_s}{\text{Grain Yield}} \qquad (10)$$

Where, CF_s is the spatial carbon footprint. Units are (kg CO_2-e ha^{-1}); CF_y is yield scaled carbon footprint. Units are (kg CO_2-e kg^{-1} yield).

Results and Discussion

Annual N_2O emissions

Annual N_2O emissions from synthetic fertilizers applied on soils

Calculated N_2O emissions from nitrogen fertilization applied on soils for wheat and corn are shown in Table 4. Data shows that the highest CO_2 emissions was found in Delta region followed by middle Egypt for both wheat and corn crops that due to the highest production and cultivation area in both regions. Egypt emissions from nitrogen fertilizers applied on soils for wheat was 0.38 and 0.48 kg N_2O per ton harvest for corn. The CO_2eq emissions from applying synthetic fertilizers on wheat and corn were 112.4 and 144.5 kg CO_2 per ton harvest, respectively. The total CO_2eq emissions from synthetic fertilizers for wheat was 949,796 and 947,207 ton CO_2 for corn.

Mineral N fertilizers are essential to sustain optimum yields that are required to satisfy the increasing global need for food and sustainable production for crops. The emissions (kg N_2O per ton harvest) for corn were higher than wheat because the amount of nitrogen added to the soil for corn was 288 and 190 kg/ha for wheat. This result is in agreement with Asgedom and Kebreab (2011) who reported that increasing N fertilizer application for the sake of providing sufficient quantity of grains to meet the ever-growing population needs has given rise to carbon emissions. Greater consideration of applying the N fertilizer at a suitable rate, proper selection of the N sources, and timing application is highly recommended. Wang et al. (2007) reported that the production and application of nitrogen fertilizers had the largest environmental impact in the winter wheat and corn production system. The maximum emissions of N_2O were recorded in the first few weeks, after the planting of wheat crop

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Table 5: Emissions of N_2O and CO_2 from application of manure on soils for wheat and corn crops

Region	Product (ton)	kg N_2O/ ton harvest	kg CO_2/ ton harvest	ton CO_2eq
		Wheat		
Delta	4,812,280	0.26	78.7	378,592
Middle Egypt	1,576,791	0.26	78.7	124,049
Upper Egypt	1,451,801	0.26	78.7	114,216
Outside valley	610,128	0.26	78.7	48,000
Egypt	8,450,999	0.26	78.7	664,857
		Corn		
Delta	3,447,527	0.38	112.4	387,463
Middle Egypt	1,774,365	0.38	112.4	199,418
Upper Egypt	1,092,874	0.38	112.4	122,827
Outside valley	240,321	0.38	112.4	27,009
Egypt	6,555,088	0.38	112.4	736,717

and overall maximum emissions of N_2O were recorded from the higher doses of N fertilizer levels, with the exception of 240kg N ha-1, N fertilizer level (Tanveer et al., 2014). Increased greenhouse gas emissions of corn grain due to nitrous oxide emissions from soil were much higher than reductions of greenhouse gas emissions of corn grain due to corn yield and changes in soil organic carbon levels at a higher nitrogen application rate (Kim and Dale, 2008).

Annual N_2O emissions from application of manure on soils

Table 5 shows the estimation of N_2O emissions from manure applied on soils for wheat and corn. The data illustrated that the lowest CO_2 emissions was found in outside valley region followed by upper Egypt for both wheat and corn crops that due to the lowest production area in both regions. Egypt emissions from manure applied on soils for wheat was 0.26 and 0.38 kg N_2O per ton harvest for corn. The CO_2eq emissions due to the use of manure for wheat and corn cultivation were 78.7 and 112.4 kg CO_2 per ton harvest, respectively. The total CO_2eq emissions from manure for wheat was 664,857 and 736,717 ton CO_2 for corn. The emissions (kg N_2O per ton harvest) for corn were higher than wheat because the amount of manure added to the soil for corn was 43 and 28 m3/ha for wheat.

The N_2O emissions were higher in soils with elevated organic matter levels, reflecting greater capacity to mineralize nitrogen and more available carbon for microbial activity as soil organic matter increased the amount of manure added to the soil for corn more than wheat. The storage and handling of manure also contribute to N2O emissions. The rate of nitrification in stored manure depends on the amount of nitrogen and the availability of oxygen necessary for the chemical reaction. Thus, nitrification does not occur in anaerobic processes. Rather, the denitrification of manure, nitrites and nitrates lead to N_2O emissions, even for anaerobic conditions. The mean value for the emission factor per kg of N applied in manure is 3.75 kg CO_2-eq/ kg N, with minimum and maximum values of 1.03 and 11.4 kg CO_2-eq/ kg- N, respectively. Due to the larger volatilization, these values are slightly smaller than for synthetic fertilizers. Manure field application is considered to be the main source of agricultural N_2O since all manure types significantly increase microbial production of N_2O from soils (Crosson et al., 2011).

Annual N_2O emissions from application of crop residues

Calculated N_2O emissions from crop residues for wheat and corn are shown in Table 6. Data shows that the highest CO_2 emissions was found in Delta region followed by middle Egypt for both wheat and corn crops. The average Egypt emissions form crop residues for wheat was 0.12 and 0.15 kg N2O per ton harvest for corn. The CO_2eq

Table 6: Emissions of N_2O and CO_2 from crop residues for wheat and corn crops

Region	Product (ton)	kg N_2O/ ton harvest	kg CO_2/ ton harvest	ton CO_2eq
		Wheat		
Delta	4,812,280	0.12	36.6	176,233
Middle Egypt	1,576,791	0.12	36.6	57,744
Upper Egypt	1,451,801	0.12	36.6	53,167
Outside valley	610,128	0.12	36.6	22,344
Egypt	8,450,999	0.12	36.6	309,488
		Corn		
Delta	3,447,527	0.15	45.5	156,863
Middle Egypt	1,774,365	0.15	45.5	80,734
Upper Egypt	1,092,874	0.15	45.5	49,726
Outside valley	240,321	0.15	45.5	10,935
Egypt	6,555,088	0.15	45.5	298,258

Table 7 (a): Emissions of CO_2 from operation machinery for wheat and corn crops

Operation	Energy-use hp-hrs/ha	Diesel Fuel (g)/ ha	Diesel Fuel (l)/ ha	CO_2 kg /ha
		Wheat		
Chisel plow	40	2.8	10.3	9
land levelling	62.5	4.3	15.9	14
Seed drill	25	1.8	6.6	6
Mower	18	1.3	4.8	4
Thresher	50	3.4	12.9	12
Combine	55	3.8	14.2	13
Total	250.7	17.2	64.6	58
		Corn		
Chisel plow	16	2.8	10.3	9
land levelling	25	4.3	15.9	14
Thresher	20	3.4	12.9	12
Total	61	10.5	39.1	35

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Table 7 (b): Emissions of CO_2 from operation machinery for wheat and corn crops

Cities	Area (ha)	Product (ton)	kg CO_2/ ton harvest	ton CO_2
Wheat				
Delta	700,651	4,812,280	8.9	42,829
Middle Egypt	226,689	1,576,791	8.9	14,033
Upper Egypt	221,011	1,451,801	8.9	12,921
Outside valley	108,925	610,128	8.9	5,430
Egypt	1,257,277	8,450,999	8.9	75,214
Corn				
Delta	391,295	3,447,527	13	44,818
Middle Egypt	228,869	1,774,365	13	23,067
Upper Egypt	146,279	1,092,874	13	14,207
Outside valley	28,261	240,321	13	3,124
Egypt	794,704	6,555,088	13	85,216

Table 8: Emissions of CO_2 from irrigation (pump water) for wheat and corn crops

Region	Irrigating m^3/ha	Energy-use PTO hp-hrs/ ha	Fuel g/ha	Fuel l/ ha	CO_2 kg/ha	Kg CO_2/ ton harvest	Ton CO_2
Wheat							
Delta	5,156	40	2.75	10.74	10	1.5	7,007
Middle Egypt	6,123	47	3.25	12.76	11	1.6	2,494
Upper Egypt	8,237	65	4.5	17.16	15	2.3	3,315
Outside valley	4,125	120	8.25	30.9	28	5	3,050
Egypt	23,641	272	19	72	16	2.6	15,865
Corn							
Delta	8,700	67	4.6	17.4	16	1.8	6,261
Middle Egypt	10,380	80	5.5	20.8	19	2.5	4,349
Upper Egypt	11,170	86	6	22.3	20	2.7	2,926
Outside valley	6,960	202	13.9	52.2	47	5.5	1,328
Egypt	37,210	436	30	113	26	3.1	14,863

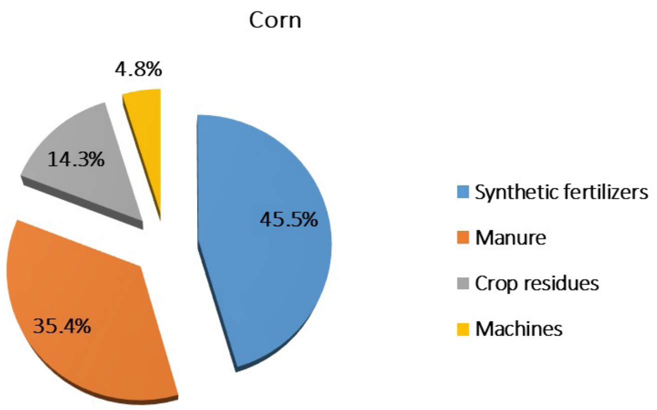

Figure 2: The average percentage of different sources of the GHG resulted from different field practices of corn production in Egypt (Source:from the calculation)

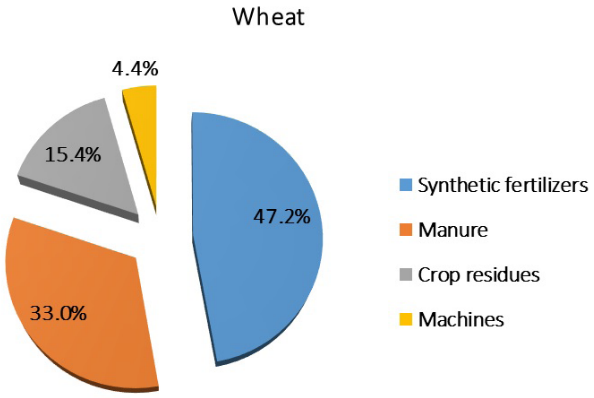

Figure 3: The average percentage of various sources of the GHG resulted from different field practices of wheat production in Egypt (Source: from the calculation)

emissions from crop residues for wheat were 36.6 and 45.5 kg CO_2 per ton for each harvest of corn. Total CO2eq emissions from crop residues for wheat and corn were 309,488 and 298,258 ton CO_2, respectively. Chen et al. (2013) reported that the plant residues with high nitrogen content (low carbon to nitrogen ratio) can speedup mineralization of the plant residues and thus increase nitrate levels in the soil beyond. The residue effects on soil N_2O emissions were positively related to the amounts of residue carbon input as well as residue effects on soil CO_2 respiration. This result is agreed with Gomes et al. (2009) who mentioned that the biochemical composition of plant residues added to the soil is responsible for higher or lower N_2O emissions because the maintenance of straw on the soil surface affects the nitrogen mobilization and immobilization, and consequently, the nitrogen availability in the soil, and also the nitrification and denitrification processes.

Annual CO_2 emissions

Annual CO_2 emissions from farm operation machinery

Farm machinery is important to achieving high yields in arid and semi-arid regions. The calculation of emissions from in seedbed preparation and mechanical operation for wheat and corn are shown in Tables 7A & 7B. Total emissions from using machines in wheat and corn fields were 58 and 35 kg CO2/ha, respectively. The highest CO_2 emissions was found in the land leveling operation (14 CO_2 kg/ha) followed by the harvesting operation, which recorded 12 CO_2 kg /ha Thresher for both wheat and corn.

The emission (kg CO_2/ton harvest) for wheat was 8.9 and 13 for corn. Total CO_2eq emissions from operating machinery for wheat and corn were 75,214 and 85,216 ton CO_2, respectively. These values are in line with research

Table 9: Emissions of total CO_2eq per hectare, GHG and carbon footprint from wheat and corn

Region	Product (ton)	ton CO_2eq/ ha	ton CO2 GHG	CFP
Wheat				
Delta	4,812,280	1.63	1,143,314	0.238
Middle Egypt	1,576,791	1.65	374,648	0.238
Upper Egypt	1,451,801	1.57	346,683	0.239
Outside valley	610,128	1.36	148,283	0.243
Egypt	8,450,999	1.55	2,012,928	0.239
Corn				
Delta	3,447,527	2.69	1,051,483	0.305
Middle Egypt	1,774,365	2.38	545,215	0.307
Upper Egypt	1,092,874	2.30	336,621	0.308
Outside valley	240,321	2.63	74,293	0.309
Egypt	6,555,088	2.50	2,007,613	0.307

by Frye and Phillips (1981), Bowers (1992), Swanton et al. (1996) and Borin et al. (1997).

Annual CO_2 emissions from irrigation (pump water)

The energy required to pump water depends on numerous factors including total dynamic head. Calculated CO_2 emissions from pumping and lifting water applied to the soils for wheat and corn are shown in Table 8. The common pump used at valley was Indian type 8 hp and outside valley submersible pump was an average of 100 hp. The highest CO_2 emissions were found in the outside valley due to pumping for different lift heights followed by Upper Egypt then Middle Egypt and finally the Delta region for both wheat and corn crops that due to pumping for different lift heights and the climate in different regions. The total Egypt emissions from pumping and lift water applied to the soils for wheat was 15,865 and 14,863 ton for corn. The CO_2 emissions pumping and lifting for wheat was 2.6 and 3.1 kg CO_2/ton harvest for corn. These findings agree with research from Batty and Keller, (1980); Singh et al. (1999); Sloggett (1992) estimated that 23% of the on-farm energy use for crop production in the US was for on-farm pumping.

The contribution of GHG emission sources for wheat and corn

Figures 2 and 3 demonstrate the percentage contributions from the different aspects and field practices for wheat and corn production. Synthetic fertilizer emissions were the main source of emissions contributing to approximately 47.2% for wheat and 45.5% for corn of the total emissions. Manure had the second largest contribution of synthetic fertilizer emissions (33 for wheat and 35.4% for corn), while the machinery activities contributed to about 4.4% for wheat and 4.8% for corn. Moreover, crop residues contributed approximately 15.4% for wheat and 14.3% for corn of the total GHGs.

This result is agreed with Al-Mansour and Jejcic (2014) who reported that the share of GHG emissions from the fertilizers used represents 42-76% of the total emissions from crop production. The carbon footprint (CF) was augmented with increasing the rate of nitrogen, except for net energy yield (NEY). The treatment of N 225 kg/ha had the highest grain yield (10 364.7 kg/ha) and NEY (6.8%), however the CF (0.25) was lower than that of N 300 kg/ha, which indicated that the rate of 225 kg N/ha can be optimal for summer corn in NCP (Wang et al., 2015).

The CO_2eq emission and carbon footprint

The calculation of total CO_2 emissions per hectare, total greenhouse gas emission (GHG), and carbon footprint for wheat and corn are shown in Table 9. Data illustrated that the lowest CO_2 emissions per hectare were found in outside valley region followed by Upper Egypt for wheat. Still, corn had the highest CO_2 emissions per hectare in the Delta region followed by outside valley. The Egypt CO_2 emissions per hectare of wheat was 1.55 and 2.50 ton CO_2/ha for corn. In Egypt, total greenhouse gas emission for wheat and corn were 2,012,928 and 2,007,613 tonnes, respectively. The carbon footprint for wheat was 0.239 and 0.307 for corn.

Increasing awareness of climate change and energy security is spurring greater investigation into how the sustainability of farming systems can be better managed to produce high-quality and affordable food in sufficient quantities while minimizing potential negative impacts on the environment. The carbon footprint of agricultural products is heavily dependent on the use of fertilizers, while productivity depends on the amount of product produced per unit of land area (Al-Mansour and Jejcic, 2016). In general, wheat had a carbon footprint value of 0.20 kg CO_2eq per kg of grain on a production level of 3.5 t/ha (Gan et al., 2012). The carbon footprint of grain production in China is based on life cycle analysis. Corn had the lowest carbon footprint, i.e., 4052 kg ce/ha of carbon per unit area or 0.48 kg ce/kg per unit yield. The carbon footprint of wheat was 5455 kg ce/ha per unit area or 0.75 kg ce/kg per unit yield (Zhang et al., 2017).

Analyzing food policy and crop production systems at the local level is critical to agricultural climate change planning to identify key influencing policies that will directly or indirectly affect CO_2 emissions and mitigation strategies (Smith et al., 2007).

Conclusions

Agricultural and rural development policies that help diversify income and employment opportunities for the poor and food insecure need to be complemented by policies that address the carbon footprint of entire crop production systems. The carbon footprint is one of the key indicators for assessing the sustainability of production in agriculture and food policy systems. The GHG emissions from the synthetic fertilizers used in all types of farming had a very high impact on the carbon footprint of grain for both crops wheat and corn. The share of GHG emissions from using the synthetic fertilizers represented 47.2 and 45.5% of the total emissions from wheat and corn cultivation. Under Egyptian condition the carbon footprint for wheat and corn was 0.239, 0.307 kg CO_2eq per kilogram of grain. An increase in productivity and optimization of nitrogen fertilizer in production will have a positive influence on decreasing the carbon footprint of agricultural products. There is a need for more studies focused on the carbon footprint of different crops under Egyptian growing conditions.

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Conflict of Interests

The authors hereby declare that there is no conflict of interests.

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