3 Methodology for Carbon Footprint Calculation in Crop and Livestock Production

Kun Cheng, Genxing Pan, Ting Luo, Ming Yan, and Qian Yue

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3.1 INTRODUCTION

The Fifth Assessment Report of IPCC (2013) reported the global mean temperature increased by 0.85°C from 1880 to 2012. Specifically, the last three decades have been warmer at the Earth's surface than any preceding decade since 1850. Global greenhouse gas (GHG) emissions due to human activities have grown rapidly by 54% between 1990 and 2011 (IPCC 2013). Rapidly increasing anthropogenic GHG emissions are making significant contribution to global climate change.

As a primary food producer, GHG emissions from agriculture contribute by 13% to the global GHG emissions, which is likely to increase in the coming decades (Smith and Gregory 2013). Fifty-six percent of the global anthropogenic non-CO_2 emissions were derived from agriculture (U.S. EPA 2012). In addition, food production and consumption accounted for almost one-fifth of total anthropogenic GHG emissions globally (Smith et al. 2014). However, indirect emissions in the process of crop production relevant to the manufacture of agricultural chemicals and farm mechanical operations also made a significant contribution to global GHG emissions.

Livestock production is already well known to contribute to GHG emissions. As reported by Food and Agriculture Organization of the United Nations (FAO), GHG emissions induced by livestock production were estimated to be 7516 million metric tons per year of CO_2 equivalents (CO_2-eq.), accounted for 18% of annual worldwide GHG emissions. Livestock production emitted 103 million tons of methane in 2004 through enteric fermentation and manure management, equivalent to 2369 million tons of CO_2-eq. In China, a large livestock producer, GHG emissions from animal enteric fermentation and manure management have been estimated at 445 Tg CO_2-eq., accounting for 45.7% of the nation's total agricultural emissions in 2005 (NDRC 2012). However, the life cycle and supply chain of domesticated animals raised for food have been vastly underestimated as a source of GHGs and in fact account for at least half of all human-caused GHGs. The above-mentioned would easily qualify livestock for a hard look indeed in the search for ways to address climate change.

The population explosion and subsequently the growing demand for resources intensify the food and energy crises and also attract increasing attentions (Steinfeld et al. 2006; FAO 2009; Godfray et al. 2010). The production of crop and livestock has been operated with maximum resource input available to reach a maximum production, though the total cropland area has been decreasing and GHGs have been emitted increasingly since the end of twentieth century (Huang 2013).

Concerns about GHG emissions reduction to mitigate climate change and food security have recently inspired the assessment of carbon footprint (CF) for various activities and products. CF, defined as a measure of the total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is emitted over the life cycles of a product, is analyzed to measure the climate change impact of products and activities in terms of the amount of GHGs emitted in a whole life cycle.

Growing interest in GHG mitigation in agriculture has provided a strong enticement to assess the CF of different agricultural production. Calculation of CF in agriculture identifies the contributions of agricultural production to climate change and the components of emission sources. Meanwhile, determining a CF of a certain agricultural product is useful for identifying how low carbon economy could be implemented to abate climate change. In this chapter, a methodology is introduced to clarify how to calculate CF of crop and livestock production according to the CF definition and life-cycle assessment method. Then an assessment approach is supplied to evaluate the CFs under different scenarios and detect climate change mitigation strategies.

3.2   GHG EMISSION SOURCES

3.2.1   System Boundaries

The system boundary for CF calculation is the farm gate of agricultural production. For crop production, the system boundary is the land boundary of studied cropland. However, the system boundary for livestock production is the farm gate of studied livestock such as dairy, sheep, pig, and so on. All agricultural inputs are traced back to production and raw material extraction and all major GHG emissions (CH_4, N_2O, and fossil CO_2) associated with inputs and farm management are accounted for.

3.2.2   GHG Emission Sources in Crop Production

CF of crop production was generally assessed by taking into account all the GHG emissions caused by or associated with material used, and farm machine operated and irrigation and drainage power exhausted for crop production in a crop life cycle (Lal et al. 2004; Hillier et al. 2009; Cheng et al. 2011). During the full life-cycle analysis of crop production, the total carbon emissions were estimated both of the direct and indirect emissions within the farm gate from crop sowing to grain harvest under a single cropping system. Hence, identifying GHG emission sources during agricultural production is the first step to conduct a CF research.

3.2.2.1   Direct Emission

3.2.2.1.1   Nitrous Oxide Emissions from Soil

Nitrous oxide (N_2O) could absorb terrestrial thermal radiation and thus contributes to global warming of the atmosphere. On a mass basis, N_2O is approximately 265 times more potent than CO_2 in a 100-year time horizon (IPCC 2013). N_2O could be generated in the processes of nitrification and denitrification in soil. In most soils, an increase in available N could enhance the nitrification and denitrification rates which then increase the production of N_2O. Available N could be supplied through human-induced N additions or change of management practices. Approximately, 58% of global N_2O emissions were from agriculture in 2005 (Smith et al. 2007). Therefore, N_2O emissions from soil could be identified as a source of CF in crop production.

3.2.2.1.2   Methane Emissions from Flooded Rice Paddy

Atmospheric concentration of methane (CH_4) has increased by 1.5 times compared with preindustrial times, accounting for 18% of the global warming potential (GWP), which ranks CH_4 as having the second highest radiative forcing of the long-lived GHGs. Rice paddies, which are characterized by relatively high organic carbon levels and prolonged anaerobic conditions during rice growth, are one of the major anthropogenic sources of CH_4 accounting for almost 20% of agricultural CH_4 emission. Carbon input and anaerobic condition are the important factors to generate CH_4. Soil type, temperature, and rice cultivar could also affect CH_4 emissions. The two main pathways for CH_4 emissions from soil to the atmosphere are transfer through rice plants and ebullition in the water. CH_4 emission from flooded rice paddy is one of the important emission sources when we calculate CF in rice production.

3.2.2.1.3   Organic Carbon Stock Changes in Soil

According to IPCC (2007), the net flux of CO_2 in agriculture is estimated to be approximately balanced though large annual CO_2 exchanges occur between the atmosphere and agricultural lands. Soil carbon sequestration is one of the most important pathways to achieve GHG mitigation potential, with an estimated 89% contribution to the technical potential. Although CO_2 emits much from soil each year, carbon input could not be ignored in the calculation of CF. In general, organic carbon stock change in soil is a thoughtful way to reflect the net CO_2 flux in cropland. Actually, carbon

stock change could not be measured in 1 year and there is also not an appropriate method to accurately calculate SOC stock change in 1 year. However, we usually assess CF for carbon production in a given year. Given these, SOC stock change is not taken into account CF calculation in this methodology.

3.2.2.1.4 *CO_2 Emissions from Machine Operation*

Farm machinery is used for spraying and tillage, harvesting, strapping, and transportation in the process of crop production. Energy, such as gasoline and diesel oil, is necessary for operating farm machinery. In this process, there is an amount of CO_2 emitted by energy consumed. CO_2 emission from machine operation should be taken into account CF calculation.

3.2.2.2 Indirect Emission

3.2.2.2.1 *GHG Emissions from Manufacturing of Agricultural Inputs*

Inputs of fertilizer, pesticide, herbicides, and plastic film are necessary to supply nutrient, protect plant health, and prevent water loss for crop production. However, there is a huge CO_2 emit when these agricultural materials are produced in the factories. These emissions occur outside the farm gate but are induced by crop production. Given these, the indirect emissions from manufacturing of agricultural materials should be thought over when assessing CF for crop production.

3.2.2.2.2 *GHG Emissions by Irrigation*

In most agricultural regions of the world, irrigation is necessary for water sully in plant growth except for rainfed cropland. Energy use for irrigation is also one of the main GHG emission sources in farming process. The main components of energy use associated with irrigation are related to processes which apply water to field by lifting, conveying or pressurizing it, and these processes could be powered by diesel or electricity (Wang et al. 2012). The emissions of GHG reasonably occur when diesel is used and electricity is generated.

3.2.3 GHG Emission Sources in Livestock Production

CF of livestock and poultry production could be generally assessed by taking into account all the GHG emissions caused by or associated with material used, farm management, and power exhausted for livestock and poultry production.

3.2.3.1 Direct Emissions

3.2.3.1.1 *Manure Treatment*

Both CH_4 and N_2O emissions occur from livestock manure management systems. Manure management account for 7% of total non-CO_2 emissions in agriculture (Smith et al. 2007). CH_4 could be emitted when confined manure management operations are conducted. However, N_2O emissions vary significantly between different manure treatment types and can also result in indirect emissions due to other forms of nitrogen loss from the system.

3.2.3.1.2 *Enteric Fermentation*

According to the FAO, 37% of human-induced methane comes from livestock production. Ruminant animals have a rumen which could produce CH_4 when microbial fermentation takes place. Cattle are an important CH_4 source in many countries due to their large population and high CH_4 emission rate by their ruminant digestive system. So emissions of CH_4 from enteric fermentation should be taken into account when CF of ruminant livestock production is estimated.

3.2.3.1.3 *Farm Management*

Machinery operation is needed especially in aggregated farm management. Machinery operation could exhaust energy such as gasoline and diesel oil which induce CO_2 emissions.

3.2.3.2 Indirect Emission

3.2.3.2.1 CO_2 Emissions from Manufacturing of Agricultural Inputs

Agricultural input includes forage, pesticides, detergents, medicines, and so on. GHG emissions occur by production and transport of these inputs. Specifically, the GHG emissions from forage input include crop cultivation, forage production, and forage transportation.

3.2.3.2.2 CO_2 Emissions from Electricity Use

Electricity is also used in livestock farms, and CO_2 emissions occur when electricity is generated. This is an indirect emission source in livestock production.

3.3 CF CALCULATION METHODS

3.3.1 CROP PRODUCTION

CF of crop production could be estimated by summarizing all the GHG emissions that is directly and indirectly caused by or associated with material used, farm management, and power exhausted over the life stages of crop production.

3.3.1.1 Direct Emissions

3.3.1.1.1 Nitrous Oxide Emissions from Soil

The direct N_2O emissions (E_{N_2O}, kg CE ha^{-1}) induced by fertilizer N input could be estimated using the following equation:

$$E_{N_2O} = N \times EF_{N_2O} \times \frac{44}{28} \times 265 \tag{3.1}$$

where N represents the amount of chemical fertilizer-N application (kg N), EF_{N_2O} is the emission factor of N_2O emission induced by N fertilizer application (kg N_2O–N kg^{-1} N fertilizer), 44/28 is the molecular weight of N_2 in relation to N_2O, 298 is the net GWP of N_2O in a 100-year horizon, and 12/44 is the molecular weight of CO_2 in relation to CE. According to IPCC (2006), EF_{N_2O} is estimated as 0.01 for dry cropland and 0.003 for rice paddy.

3.3.1.1.2 Methane Emissions from Flooded Rice Paddy

Seasonal CH_4 emissions from rice paddies should be estimated for rice CF calculation. Direct CH_4 emissions are estimated using the IPCC's methodology (IPCC 2006) with the equation:

$$E_{CH_4} = EF_d \times t \times A \times 28 \tag{3.2}$$

$$EF_d = EF_c \cdot SF_w \cdot SF_p \cdot SF_o \cdot SF_{s,r} \tag{3.3}$$

$$SF_o = \left(1 + \sum_i ROA_i \cdot CFOA_i\right)^{0.59} \tag{3.4}$$

where E_{CH_4} represents the GHG emissions (kg CO_2-eq.) from CH_4 emitted from rice paddy in a single season, EF_d is a daily emission factor (kg CH_4/ha/day), t is rice growing period (days), A is area of rice paddy (ha), and 28 is the relative molecular warming forcing of CH_4 in a 100-year horizon (IPCC 2013), EF_c is the emission factor for continuously flooded fields without organic amendments, SF_w represents scaling factor to account for the differences in water regime during the rice

growing period, SF_p represents scaling factor to account for the differences in water regime in the preseason before the rice growing season, SF_o represents scaling factor should vary for both type and amount of organic amendment applied (Equation 3.4), $SF_{s,r}$ represents scaling factor for soil type, rice cultivar, and so on, if these factors are available. ROA_i is the application rate of organic amendment i, in dry weight for straw and fresh weight for others (kg/ha), and $CFOA_i$ is the conversion factor for organic amendment i.

3.3.1.1.3 CO_2 Emissions from Machine Operation

CO_2 emissions from machine operation could be calculated according to the amount of fuel, net caloric value of a given fuel and emission factor of this fuel, as shown in Equation 3.5:

$$E_M = \sum_i (EF_i \cdot W_i \cdot NCV_i) \tag{3.5}$$

where E_M is the CO_2 emissions from machine operation (kg CO_2-eq.), W_i is the amount of fuel i consumed (t or L), NCV_i represents net caloric value for fuel i (GJ/kg or L), EF_i represents emission factor for fuel i (kg CO_2-eq./GJ).

3.3.1.2 Indirect Emissions

3.3.1.2.1 GHG Emissions from Manufacturing of Agricultural Inputs

GHG emissions induced by manufacturing of individual materials used for crop production, protection and management including fertilizer, pesticides, and plastic film, which is calculated using Equation 3.6:

$$E_{AI} = \sum AI \times EF_{AI} \tag{3.6}$$

where E_M is GHG emissions by manufacturing of individual materials such as fertilizer, pesticide, agricultural film, and so on (kg CO_2-eq.), AI denotes the amount of a kind of agricultural inputs in kg ha^{-1}, and EF is the emission factor of manufacturing a unit of the input material (kg CO_2-eq. kg^{-1}).

3.3.1.2.2 GHG Emissions by Irrigation

The energy use for irrigation, which would be one of the main GHG emission sources in farm operations, is also calculated. The main components of energy use associated with irrigation are related to pumping water to field, being generally powered either by diesel or by electricity (Wang et al. 2012). In general, GHG emissions induced by irrigation (E_{IRRI}, kg CE ha^{-1}) could be calculated using the approach developed by Wang et al. (2012):

$$E_{IRRI} = IR_{ij} \times EF_j \tag{3.7}$$

where IR_{ij} represents the amounts of water irrigated for crop i in region j in m^3 and EF_j is the emission factor of irrigation for region j in kg CO_2-eq. m^{-3}.

3.3.1.3 CF Assessment

Overall, the total CF of grain crop in a single cropping season in terms of land used (CF_A, kg CO_2-eq./ha) was assessed by summarizing all of the individual GHG emissions mentioned above:

$$CF_A = \frac{E_{N_2O} + E_{CH_4} + E_M + E_{AI} + E_{IRRI}}{A} \tag{3.8}$$

where A is the total area of studied field (ha).

With the estimated CF_A, CF in terms of grain production (CF_Y, kg CO$_2$-eq./kg grain produced) (GHG intensity in other words) was evaluated using Equation 3.9:

$$CF_Y = \frac{CF_A}{Y} \tag{3.9}$$

where Y denotes grain yield of a given crop (kg/ha).

3.3.2 Livestock Production

CF of livestock production was generally assessed by taking into account all the GHG emissions caused by or associated with material used, farm management, and energy exhausted for livestock production. A life-cycle assessment (LCA) and input–output analysis was used to describe the total GHG emissions by livestock production. CF calculated was expressed in carbon dioxide equivalent (CO$_2$-eq.) per unit livestock production.

3.3.2.1 Direct Emission

3.3.2.1.1 CH$_4$ Emissions from Enteric Fermentation

CH$_4$ is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream (IPCC 2006). The CH$_4$ emissions from enteric fermentation are estimated using Equation 3.10:

$$E_{EF} = H \times EF_{EF} \times 28 \tag{3.10}$$

where E_{EF} is the CH$_4$ emissions from enteric fermentation (kg CO$_2$-eq.), H denotes the number of ruminant head, EF_{EF} is the emission factors for enteric fermentation (kg CH$_4$/head/a), and 28 is the net GWP of CH$_4$ in a 100-year horizon.

3.3.2.1.2 N$_2$O and CH$_4$ Emissions by Manure Treatment

Livestock production can result in both CH$_4$ and N$_2$O emissions from livestock manure management systems which are main GHG sources in agricultural sector. CH$_4$ and N$_2$O emissions during manure treatment (E_M, kg CO$_2$-eq.) are estimated using Equations 3.11 through 3.13:

$$E_M = H \times EF_{CH_4} \times 28 + (N_2O_{D(mm)} + N_2O_{G(mm)}) \times 265 \tag{3.11}$$

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T (N_T \times Nex_{(T)} \times MS_{(T,S)}) \right] \times EF_{3(S)} \right] \times \frac{44}{28} \tag{3.12}$$

$$N_2O_{G(mm)} = \left[\sum_S \left[\sum_T (N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}) \times \left(\frac{Frac_{GasMS}}{100} \right)_{(T,S)} \right] \times EF_4 \right] \times \frac{44}{28} \tag{3.13}$$

where H denotes the number of head (head), EF_{CH_4} is the CH$_4$ emission factor (kg CH$_4$/head/a), $N_2O_{D(mm)}$ the direct emissions of nitrous oxide under manure management system (kg N$_2$O/a), $N_2O_{G(mm)}$ the indirect nitrous oxide emissions of manure management system (kg N$_2$O/a), the direct and indirect N$_2$O emission from manure treatment are calculated using the second method

recommended by IPCC (2006), 298 is the net GWP of N_2O in a 100-year horizon, $N_{(T)}$ is the number of head of livestock species/category T in the given region, $Nex_{(T)}$ is the annual average N excretion per head of species/category T in the country (kg N/animal/year), $MS_{(T,S)}$ is the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the given region (dimensionless), $EF_{3(S)}$ is the emission factor for direct N_2O emissions from manure management system S in the country (kg N_2O-N/kg N) in manure management system S, $Frac_{GasMS}$ is the percent of managed manure nitrogen for livestock category T that volatilizes as NH_3 and NO_x in the manure management system S (%), S is manure management system, T is species/category of livestock, EF_4 is the emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3–N + NO_x–N volatilized)$^{-1}$, default value is 0.01 kg N_2O-N (kg NH_3–N + NO_x–N volatilized)$^{-1}$, 44/28 is conversion of (N_2O–N) (mm) emissions to N_2O (mm) emissions.

3.3.2.1.3 Energy Use in Farm Management

The GHG emissions from energy use induced by farm management (CF_M, kg CO_2-eq.) include fuel and electricity consumed in the process of farm management. These emissions could be calculated by Equations 3.14 and 3.15:

$$E_F = \sum_i (EF_i \cdot W_i \cdot NCV_i) \tag{3.14}$$

$$E_E = E \times EF_E \tag{3.15}$$

where E_F is CO_2 emissions from fuel use (kg CO_2-eq.), W_i is the amount of fuel i consumed (t or L), NCV_i represents net caloric value for fuel i (GJ/kg or L), EF_i represents emission factor for fuel i (kg CO_2-eq./GJ). E is the amount of electricity used in the life-cycle analysis of livestock production (kw h) and EF_E represents emission factor for electricity generation (kg CO_2-eq./kw h).

3.3.2.2 Indirect Emissions

3.3.2.2.1 GHG Emissions from Manufacture of Forage

According to the field survey conducted by previous study, the types of forage include mixed forage, self-made forage, concentrates, and green forage. The GHG emissions from manufacture of forage include crop cultivation, forage processing, and forage transportation. In general, these emissions could be estimated using the following equation:

$$E_{Forge} = F_C \times EF_C + F_P \times EF_P + E_T \tag{3.16}$$

where E_{Forge} is the GHG emissions by forge input, F_C is the amount of crop production used for forge manufacture (kg), EF_C represents the emission factor for a given crop production (kg CO_2-eq./kg production); F_P means the amount of forge used in livestock production (kg), EF_P denotes emission factor in forage processing (kg CO_2-eq./kg forge produced). E_T is the GHG emissions by forage transportation calculated by multiplying amount of fuel consumption by emission factor of fuel.

3.3.2.3 Assessment of CF of Livestock Production

Overall, total CF of livestock production could be assessed by summarizing all of individual GHG emissions mentioned above:

$$CF = E_{EF} + E_M + E_F + E_E + E_{Forage} \tag{3.17}$$

With the estimated CF, CF in terms of livestock and poultry production (CF_P, kg CO_2-eq./kg production) (GHG intensity in other words) was calculated using Equation 3.18:

$$CF_P = \frac{CF}{P} \tag{3.18}$$

where P denotes the production of a given livestock (kg).

3.4 DATA SOURCES

3.4.1 EMISSION FACTORS

3.4.1.1 Crop Production

Assessment of CF in crop production need various emission factors including emission factors of direct N_2O emission by N input, CH_4 emission from rice paddy, CO_2 emission by fuel combustion, carbon dioxide respired by an adult, manufacture of agricultural inputs, and energy use in irrigation.

1. *Emission factors of direct N_2O emission by N input*
   Direct N_2O emission factors have been developed by IPCC (2006) and some studies over the world. Some emission factors developed are listed in Table 3.1. However, the region-specific emission factors should be used in CF assessment in these regions if available.
2. *Emission factors of direct CH_4 emission from rice paddy*
   All the emission and scaling factors relate to calculate CH_4 emissions from rice paddy are listed in Tables 3.2 through 3.5 according to IPCC methodology (IPCC 2006). Region-specific emission factors should be used in CF assessment in these regions if available.

TABLE 3.1
Emission Factor of N Fertilizer-Induced N_2O Emissions

Abbreviation	Emission Factor	Condition	Region	Literature
EF_{N_2O}	0.01 tN_2O–N/t fertilizer-N	Mineral soil	Global	IPCC (2006)
	0.003 tN_2O–N/t fertilizer-N	Rice paddy	Global	IPCC (2006)
	0.0002 tN_2O–N/t fertilizer-N	F[a] in rice paddy	China	Zou et al. (2007)
	0.0042 tN_2O–N/t fertilizer-N	F-D-F[a] in rice paddy	China	Zou et al. (2007)
	0.0073 tN_2O–N/t fertilizer-N	F-D-IF-M[a] in rice paddy	China	Zou et al. (2007)
	0.0186P[b] tN_2O–N/t fertilizer-N	Mineral soil	China	Lu et al. (2006)

[a] F: flood; D: drainage; IF: intermittent flood; M: moist but nonwaterlogged by intermittent irrigation.
[b] P: annual precipitation, m.

TABLE 3.2
Default CH_4 Baseline Emission Factor

Abbreviation	Emission Factor[a] (kg CH_4 ha^{-1} day^{-1})
EF_c	1.30

Source: Adapted from Yan et al. (2005).

[a] It was assumed that no flooding for less than 180 days prior to rice cultivation, and continuously flooded during rice cultivation without organic amendments.

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TABLE 3.3
Default CH$_4$ Emission Scaling Factors for Water Regimes During the Rice Season

		Scaling Factor (SF_w)	
	Water Regime	**Aggregated Case**	**Disaggregated Case**
	Upland[a]	0	0
Irrigated[b]	Continuously flooded	0.78	1
	Intermittently flooded—single aeration		0.6
	Intermittently flooded—multiple aeration		0.52
Rainfed and	Regular rainfed (50 cm)	0.27	0.28
deep water[c]	Drought prone		0.25
	Deep water (more than 50 cm for a significant period of time)		0.31

Source: Adapted from Yan et al. (2005).

[a] Fields are never flooded for a significant period of time.

[b] Fields are flooded for a significant period of time and water regime is fully controlled.
   - *Continuously flooded:* Fields have standing water throughout the rice growing season and may only dry out for harvest (end-season drainage).
   - *Intermittently flooded:* Fields have at least one aeration period of more than 3 days during the cropping season.
     - *Single aeration:* Fields have a single aeration during the cropping season at any growth stage (except for end-season drainage).
     - *Multiple aeration:* Fields have more than one aeration period during the cropping season (except for end-season drainage).

[c] Fields are flooded for a significant period of time and water regime depends solely on precipitation.

TABLE 3.4
Default CH$_4$ Emission Scaling Factors for Water Regimes Before the Cultivation Period

	Scaling Factor (SF_p)	
Water Regime Prior to Rice Cultivation	**Aggregated Case**	**Disaggregated Case**
Non flooded preseason <180 days		1
Non flooded preseason >180 days	1.22	0.68
Flooded preseason (>30 days)[a]		1.9

Source: Adapted from Yan et al. (2005).

[a] Short preseason flooding periods of less than 30 days are not considered in selection of SF_p.

TABLE 3.5
Default Conversion Factor for Different Types of Organic Amendment

Organic Amendment	**Conversion Factor (CFOA)**
Straw incorporated shortly (<30 days) before cultivation[a]	1
Straw incorporated long (>30 days) before cultivation[a]	0.29
Compost	0.05
Farm yard manure	0.14
Green manure	0.50

Source: Adapted from Yan et al. (2005).

[a] Straw application means that straw is incorporated into the soil; it does not include case that straw just placed on the soil surface nor that straw was burnt on the field.

TABLE 3.6

Default Net Calorific Values (NCVs) of Main Kinds of Fuel

Abbreviation	Fuel Type	Net Calorific Value (TJ/Gg)
NCV_i	Motor gasoline	44.3
	Aviation gasoline	44.3
	Jet gasoline	44.3
	Gas/diesel oil	43.0
	Biogasoline	27.0
	Biodiesels	27.0

Source: Adapted from IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. National Greenhouse Gas Inventories Programme. Tokyo, Japan: IGES.

3. *Emission factors of fuel combustion*
   Net caloric values and emission factors for main kinds of fuel are shown in Tables 3.6 and 3.7 according to IPCC (2006).
4. *Carbon dioxide respired by an adult*
   Carbon dioxide respired by an adult is 0.9 kg CO_2-eq. day^{-1} person^{-1} (Yang 1996).
5. *Emission factors of manufacture of agricultural inputs*
   Emission factors of manufacture of agricultural inputs vary largely among different regions and techniques of production. However, there are limited studies focused on development emission factors of these. Herewith, this chapter lists some emission factors by previous studies (Table 3.8). Specific emission factor development is an essential research field in future.
6. *Emission factor of irrigation*
   Emission factors of irrigation have been developed by researches for some regions (Table 3.9). For example, emission factors of irrigation in each province of China have been developed, and the details of this calculator were also presented in the study of Wang et al. (2012). However, region-specific emission factors for irrigation should be developed in further studies for the precise of CF calculation.

3.4.1.2 Livestock Production

1. *CH_4 emission factor of enteric fermentation*
   The amount of CH_4 that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed (IPCC 2006). The emission factor could be found in Tables 3.10a and 3.10b according to IPCC (2006).

TABLE 3.7

Default CO_2 Emission Factors for Main Kinds of Fuel Combustion

Abbreviation	Fuel Type	Default CO_2 Emission Factor (kg CO_2/TJ)
EF_i	Motor gasoline	69,300
	Aviation gasoline	70,000
	Jet gasoline	70,000
	Gas/diesel oil	74,100
	Biogasoline	70,800
	Biodiesels	70,800

Source: Adapted from IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. National Greenhouse Gas Inventories Programme. Tokyo, Japan: IGES.

TABLE 3.8
Emission Factors for Manufacturing Fertilizer, Pesticide, and Plastic Film

Abbreviation	Emission Source	Emission Factor	Region	Literature
EF_{AI}	N fertilizer	6.38 kg CO_2-eq. kg^{-1} N	China	Lu et al. (2008)
	N fertilizer	10.85 kg CO_2-eq. kg^{-1} N	Scotland, UK	Hillier et al. (2009)
	N fertilizer	4.95 kg CO_2-eq. kg^{-1} N	United States	Dubey and Lal (2009)
	P fertilizer	0.73 kg CO_2-eq. kg^{-1} P_2O_5	United States	Dubey and Lal (2009)
	K fertilizer	0.55 kg CO_2-eq. kg^{-1} K_2O	United States	Dubey and Lal (2009)
	Farmyard manure	0.55 kg CO_2-eq. kg^{-1}	Scotland, UK	Hillier et al. (2009)
	Insecticides	17.05 kg CO_2-eq. kg^{-1}	United States	Dubey and Lal (2009)
	Insecticides	1.32 kg CO_2-eq. kg^{-1}	Scotland, UK	Hillier et al. (2009)
	Herbicides	26.22 kg CO_2-eq. kg^{-1}	United States	Dubey and Lal (2009)
	Herbicides	23.1 kg CO_2-eq. kg^{-1}	Scotland, UK	Hillier et al. (2009)
	Fungicide/nematicide	11.59 kg CO_2-eq. kg^{-1}	Scotland, UK	Hillier et al. (2009)
	Film	18.99 kg CO_2-eq. kg^{-1}	China	Cheng et al. (2011)

TABLE 3.9
Emission Factors for Irrigation

Abbreviation	Emission Factor	Region	Literature
EF_j	91.67 kg CO_2-eq. ha^{-1}	Punjab, India	Dubey and Lal (2009)
	0.49 kg CO_2-eq. m^{-3}	Hebei province, China	Wang et al. (2012)
	0.30 kg CO_2-eq. m^{-3}	Inner Mongolia, China	Wang et al. (2012)
	0.21 kg CO_2-eq. m^{-3}	Liaoning province, China	Wang et al. (2012)
	0.50 kg CO_2-eq. m^{-3}	Gansu province, China	Wang et al. (2012)
	0.40 kg CO_2-eq. m^{-3}	Hunan province, China	Wang et al. (2012)

TABLE 3.10a
Emission Factors for Enteric Fermentation

Abbreviation	Livestock	Developed Countries (kg CH_4 $head^{-1}$ $year^{-1}$)	Developing Countries (kg CH_4 $head^{-1}$ $year^{-1}$)	Liveweight (kg)
EF_{EF}	Buffalo	55	55	300
	Sheep	8	5	65 (developed countries); 45 kg (developing countries)
	Goats	5	5	40
	Camels	46	46	570
	Horses	18	18	550
	Mules and Asses	10	10	245
	Deer	20	20	120
	Alpacas	8	8	65
	Swine	1.5	1.0	

Source: Adapted from IPCC. 2006. 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. National Greenhouse Gas Inventories Programme. Tokyo, Japan: IGES.

TABLE 3.10b
Enteric Fermentation Emission Factors for Cattle

Region	Cattle Category	Emission Factors (kg CH_4/head/year)	Comments
North America	Dairy	128	Average milk production of 8400 kg head^{-1} year^{-1}
	Other Cattle	53	Includes beef cows, bulls, calves, growing steers/heifers, and feedlot cattle
Western Europe	Dairy	117	Average milk production of 6000 kg head^{-1} year^{-1}
	Other Cattle	57	Includes bulls, calves, and growing steers/heifers
Eastern Europe	Dairy	99	Average milk production of 2550 kg head^{-1} year^{-1}
	Other Cattle	58	Includes beef cows, bulls, and young
Oceania	Dairy	90	Average milk production of 2200 kg head^{-1} year^{-1}
	Other Cattle	60	Includes beef cows, bulls, and young
Latin America	Dairy	72	Average milk production of 800 kg head^{-1} year^{-1}
	Other Cattle	56	Includes beef cows, bulls, and young
Asia	Dairy	68	Average milk production of 1650 kg head^{-1} year^{-1}
	Other Cattle	47	Includes multi-purpose cows, bulls, and young
Africa and Middle East	Dairy	46	Average milk production of 475 kg head^{-1} year^{-1}
	Other Cattle	31	Includes multi-purpose cows, bulls, and young
Indian Subcontinent	Dairy	58	Average milk production of 900 kg head^{-1} year^{-1}
	Other Cattle	27	Includes cows, bulls, and young. Young comprise a large portion of the population

Source: Adapted from IPCC. 2006. 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. National Greenhouse Gas Inventories Programme. Tokyo, Japan: IGES.

2. *Emission factors of manure management*
   The main factors affecting CH_4 emissions are manure production and the portion of the manure that decomposes anaerobically. Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The CH_4 emission factors could be found in Annex 10A.2 in Chapter 10 of IPCC (2006), whereas the N_2O emission factors could be obtained in Tables 10.19 and 10.20 in Chapter 10 of IPCC (2006).

3. *Emission factors of fuel and electricity consumed*
   Net caloric values and emission factors for main kinds of fuel are shown in Tables 3.6 and 3.7 according to IPCC (2006). Emission factor of electricity generation is shown in Table 3.11. However, region-specific emission factors should be used when CFs of livestock production are calculated in these region if available.

4. *Carbon dioxide respired by an adult*
   Carbon dioxide respired by an adult is 0.9 kg CO_2-eq. day^{-1} person^{-1} (Yang 1996).

5. *Emission factors of manufacture of forge*
   According to the description above, GHG emissions from manufacture of forage include crop cultivation, forage processing, and forage transportation. Emissions from transportation could be calculated by the emission factors supplied in Tables 3.6 and 3.7. Emission factors of crop cultivation actually are the CF of crop production used in forge production, which could be estimated by the approach supplied by this chapter or just obtain from

TABLE 3.11

Emission Factors for Electricity Generation

Abbreviation	Region	Emission factors (kg CO$_2$-eq./kW h)	Reference
EF_E	Global	0.538	CER (2007)
	North China	1.0302	The NDRC climate
	Northeast China	1.1120	division (2013)
	East China	0.8100	
	Middle China	0.9779	
	Northwest China	0.9720	
	South China	0.9223	

previous studies. There are limited studies focused on the development of emission factors by forge processing, which should be conducted in future studies.

3.4.2 ACTIVITY DATA

3.4.2.1 Statistical Data

There are national or regional statistical yearbooks in the government of each country and region. Annually, being one of the most important sections, agriculture production data should be involved in these yearbooks. Therefore, input data for CF calculation could be collected from various yearbooks that reported agricultural production statistical data. The input data requested by CF calculation of crop production include crop yields, cultivated area, as well as the amounts of various agricultural inputs including fertilizer, pesticide, agricultural plastic film, irrigated water, diesel use during crop production. However, the input data, including scale of livestock production, yield of livestock, manure treatment method, and amounts of manure, as well as the amount of individual agricultural inputs consist of forge, fuel, and electricity, should be collected for livestock production CF calculation. The input data requested is listed in Tables 3.12 and 3.13 for crop and livestock production, respectively.

3.4.2.2 Field Survey Data

Field survey data are also an important source for CF study. Data collection could be performed by face-to-face interview with farmers during crop and livestock harvest each year. Data describing material and energy inputs for crop and livestock production in a single crop production cycle or a whole year should be recorded to create a database. During the survey, a number of farms should be randomly selected for the field questionnaire survey according to local scare. The data for a single cropping season inquired with the interview include: (a) locations of farms and contacts of farmers; (b) amounts of fertilizers (N, P, K) and pesticides used; (c) machinery operation for spraying, tillage,

TABLE 3.12

Data Request for CF Calculation in Crop Production

No.	Location	Cultivated Area (ha)	Yield (kg)	N Fertilizer (kg N/ha)	P Fertilizer (kg P$_2$O$_5$/ ha)	K Fertilizer (kg K$_2$O/ ha)	Other Fertilizer (kg/ha)	Pesticide (kg/ha)	Film (kg/ha)	Irrigation (m³/ha)	Fuel (L or kg/ha)
Region 1											
Region 2											
Region 3											
…											

TABLE 3.13

Data Request for CF Calculation in Livestock Production

No.	Location	Scale (Heads)	Yield (kg/year)	Forge (kg/head)	Electricity (kW h)	Fuel (L or kg)	Manure Treatment Method	Manure (kg/year)
Region 1								
Region 2								
Region 3								
…								

TABLE 3.14

Data Surveyed for CF Calculation in Crop Production

No.	Location	Cultivated Area (ha)	Yield (kg)	N Fertilizer (kg N)	P Fertilizer (kg P_2O_5)	K Fertilizer (kg K_2O)	Other Fertilizer (kg)	Pesticide (kg)	Film (kg)	Irrigation (m^3)	Fuel (L or kg)
Site 1											
Site 2											
Site 3											
…											

TABLE 3.15

Data Surveyed for CF Calculation in Livestock Production

No.	Location	Scale (Heads)	Yield (kg/year)	Forge (kg/year)	Electricity (kW h/year)	Fuel (L or kg/year)	Manure Treatment Method	Manure (kg/year)
Site 1								
Site 2								
Site 3								
…								

harvesting, and transportation as well as for irrigation; (d) cropping system and water regime management for rice paddy; (e) farm size and the total grain produced. The obtained data for CF calculation of livestock production include: (a) location of a farm and the contacts of farmers; (b) scale of a farm, (c) amounts of forage, fuel, and electricity; (d) manure treatment method and amounts of manure, (e) annual yield of livestock production. The requested data are listed in Tables 3.14 and 3.15 for the field survey of crop and livestock production, respectively.

3.5 CASE STUDIES

3.5.1 CF of Main Grain Crop Production in Shandong Province of China

3.5.1.1 Scope and Objective

Wheat and corn are the major grain crops, accounting for almost 64% of total arable land area in China (FAOSTAT 2014). Shandong Province is one of the most important grain crop producers in China. The yields of wheat and maize in Shandong province accounted for 18 and 10% of total wheat and maize in China, respectively. In order to meet the food demand by the increasing population, production of these crops has been achieved with maximum available input of resources to reach a maximum yield. In addition, these two grain crops could have significant contributions to agricultural

GHG emissions. Given that determining the CF of crop production is useful for identifying how low carbon economy could be implemented to abate climate change, this case study was aimed to quantify the CFs of the two grain crops in Shandong province. Special attention has been given to the contribution of individual inputs to total CF in crop production. In addition, sensitivity analysis was conducted to assess the sensitivity of the total CF to different factors considered in this study.

3.5.1.2 Data Source

Input data for CF calculation includes crop grain yields, the amounts of various agricultural inputs including fertilizer, pesticide, agricultural plastic film, irrigated water, and diesel in 2012. The original data were available from "Compilation of the national agricultural costs and returns" and "Yearbook of China water resources." The data collected for CF calculation was shown in Table 3.16.

3.5.1.3 CF Calculation

The "farm gate" (up to harvest) was considered as the boundary of this study. Therefore, the direct emissions from soil N_2O and CH_4 emissions, machine operation, and indirect emissions from manufacturing of agricultural inputs and irrigation in wheat and maize production were considered for CF calculation up to the "farm gate" (up to harvest).

3.5.1.3.1 Direct Emissions

3.5.1.3.1.1 Nitrous Oxide Emissions from Soil   For maize field,

$$E_{N_2O} = N \times EF_{N_2O} \times \frac{44}{28} \times 265 = 170.69 \times 0.0186 \times 0.75 \times \frac{44}{28} \times 265 = 991.57 \quad (\text{kg}\,CO_2\text{-eq./ha})$$

For wheat field,

$$E_{N_2O} = 197.55 \times 0.0186 \times 0.75 \times \frac{44}{28} \times 265 = 1147.6 \quad (\text{kg}\,CO_2\text{-eq./ha})$$

3.5.1.3.1.2 Methane Emissions from Flooded Rice Paddy   There is no CH_4 emission in maize and wheat field, therefore, $E_{CH_4} = 0$.

3.5.1.3.1.3 CO$_2$ Emissions from Machine Operation   For maize field,

$$E_M = \sum_i (EF_i \cdot W_i \cdot NCV_i) = 74{,}100 \times 131.40 \times 43 \times 10^{-6} = 418.68 \quad (\text{kg}\,CO_2\text{-eq./ha})$$

For wheat field,

$$E_M = 74{,}100 \times 207 \times 43 \times 10^{-6} = 659.56 \quad (\text{kg}\,CO_2\text{-eq./ha})$$

TABLE 3.16

Original Data for CF Calculation of Grain Crop Production

Crop	N Fertilizer (kg/ha)	P Fertilizer (kg/ha)	K Fertilizer (kg/ha)	Film (kg/ha)	Pesticide (kg/ha)	Diesel (kg/ha)	Irrigation (m³/ha)	Yield (kg/ha)
Maize	170.69	86.41	48.75	0	9.39	131.40	945	7515.75
Wheat	197.55	115.50	60.45	0	7.81	207.00	2400	6546.75

3.5.1.3.2 Indirect Emissions

3.5.1.3.2.1 *GHG Emissions from Manufacturing of Agricultural Inputs*   For maize production,

$$E_{AI} = \sum AI \cdot EF_{AI} = 170.69 \times 6.38 + 86.41 \times 0.73 + 48.75 \times 0.55 + 9.39 \times 17.05$$
$$= 1338.99 \quad (\text{kg CO}_2\text{-eq./ha})$$

For wheat production,

$$E_{AI} = 197.55 \times 6.38 + 115.5 \times 0.73 + 60.45 \times 0.55 + 7.81 \times 17.05 = 1511.09 \quad (\text{kg CO}_2\text{-eq./ha})$$

3.5.1.3.2.2 *GHG Emissions by Irrigation*   For maize production,

$$E_{IRRI} = IR_{ij} \times EF_j = 945 \times 0.26 = 245.7 \quad (\text{kg CO}_2\text{-eq./ha})$$

For wheat production,

$$E_{IRRI} = IR_{ij} \times EF_j = 2400 \times 0.26 = 624 \quad (\text{kg CO}_2\text{-eq./ha})$$

3.5.1.3.3 CF Assessment

For maize production,

$$CF_A = \frac{E_{\text{N}_2\text{O}} + E_{\text{CH}_4} + E_M + E_{Labor} + E_{AI} + E_{IRRI}}{A} = \frac{991.57 + 0 + 418.68 + 1338.99 + 245.7}{1}$$
$$= 2994.94 \quad (\text{kg CO}_2\text{-eq./ha})$$

$$CF_Y = \frac{CF_A}{Y} = \frac{2994.94}{7515.75} = 0.40 \quad (\text{kg CO}_2\text{-eq./kg yield})$$

For wheat production,

$$CF_A = \frac{1147.6 + 0 + 659.56 + 1511.09 + 624}{1} = 3942.25 \quad (\text{kg CO}_2\text{-eq./ha})$$

$$CF_Y = \frac{3942.25}{6546.75} = 0.60 \quad (\text{kg CO}_2\text{-eq./kg yield})$$

3.5.1.4 Results

The CFs of maize and wheat production were calculated based on the CF methodology provided by this chapter. As shown in Figure 3.1, wheat production had the higher CFs being 3942.25 kg CO_2-eq./ha and 0.6 kg CO_2-eq./kg yield than maize production with the CFs of 2994.94 kg CO_2-eq./ha and 0.4 kg CO_2-eq./kg yield.

Proportions of different inputs in CF were calculated to assess the contribution of each emission source to total CF (Figure 3.2). Both for maize and wheat production, most of the CF (70 and 61%, respectively) was derived from N fertilizer application including N_2O emissions from soil and GHG emissions from manufacturing of N fertilizer. Machine operation turned to be the second biggest
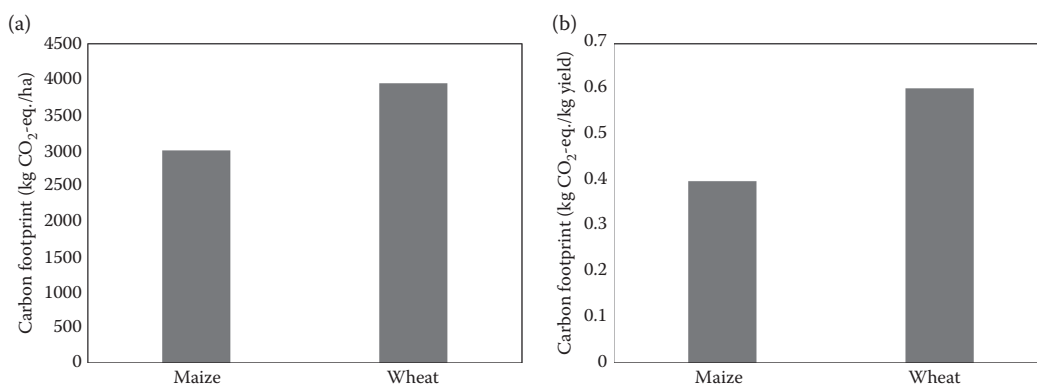
(a)

(b)

FIGURE 3.1 CFs in terms of land use (a) and grain yield (b) in maize and wheat production in Shandong, China.
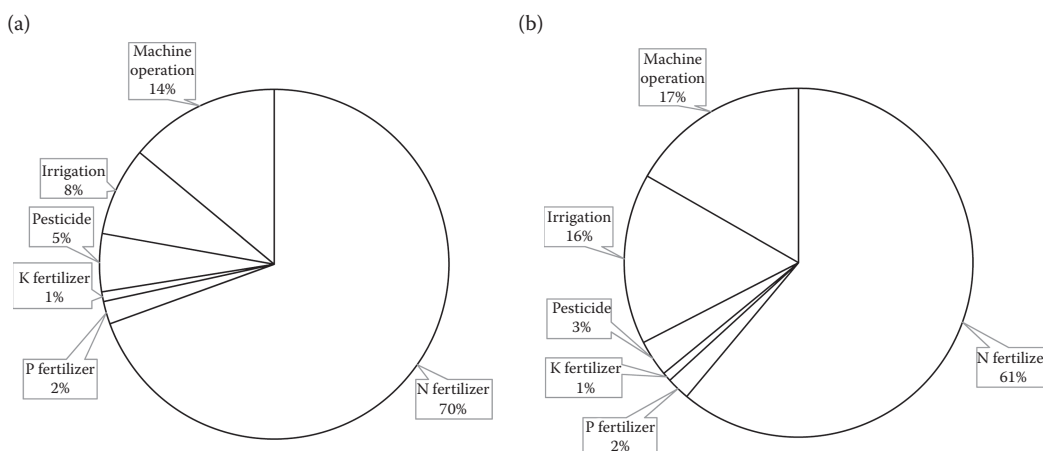
(a)

(b)

FIGURE 3.2 Contributions of agricultural inputs to total CF of maize (a) and wheat production (b).

contributor by 14% in maize production. However, machine operation and irrigation made the similar contribution (17 and 16%, respectively) to total CF in wheat production which is different from maize production with a contribution of only 8% in irrigation.

3.5.1.5 Sensitivity Analysis

The sensitivity of the total CF to different inputs and grain yield was evaluated in this study, including fertilizer, irrigation, pesticide, machine operation, and grain yield, respectively. As shown in Table 3.17, the calculated CF responded differently to changes in the different parameters, which were increased and decreased by 10% in our evaluation. The most sensitive parameter was grain yield (9.09 and −9.09% for 10% decrement and increment, respectively) and N fertilizer input (6.95 and −6.95% for 10% decrement and increment in maize production, and 6.11 and −6.11% for 10% decrement and increment in wheat production, respectively) for both maize and wheat production. The sensitivity of K fertilizer had a much smaller influence on CF in our evaluation. Sensitivity analysis gave us a suggestion that the reliability of data sources of these inputs is a key factor to obtain the accurate CF results. These also indicated that the increase in grain production and N fertilizer use efficiency could be a strategy to reduce CF in grain crop production.

TABLE 3.17
Sensitivity Analysis of Various Agricultural Inputs
and Grain Yield to Total CF (in %)

	Maize		Wheat	
Item	−10%	10%	−10%	10%
N fertilizer	−6.95	6.95	−6.11	6.11
P fertilizer	−0.21	0.21	−0.21	0.21
K fertilizer	−0.09	0.09	−0.08	0.08
Pesticide	−0.53	0.53	−0.34	0.34
Irrigation	−0.82	0.82	−1.58	1.58
Machine operation	−1.40	1.40	−1.67	1.67
Yield	9.09	−9.09	9.09	−9.09

3.5.1.6   Conclusions

The production of wheat and maize in Shandong province of China shows CFs of 0.6 and 0.4 kg CO_2-eq./kg grain, respectively, mainly due to N fertilizer inputs and machine operation. This chapter highlights opportunities for GHG mitigation by improving N fertilizer use efficiency and increasing grain yield in crop production of Shandong province of China.

3.5.2   CF of Milk Production Based on a Site Survey in Sichuan Province, China

3.5.2.1   Scope and Objective

China's livestock production ranks first in the world, and GHG emissions from animal enteric fermentation and manure management have been estimated at 445 Tg CO_2-eq., accounting for 45.7% of the nation's total agricultural emissions in 2005 (NDRC 2012). Thus, livestock production in China could play a key role in global climate change. To identify the contributions of livestock production to climate change and the key mitigation options, quantifying and assessing the CF in China's livestock and poultry production is urgently required. According to statistical data, Sichuan province is one of the largest livestock producer in China with the output of pork, poultry, eggs, and milk being 4.964, 0.93, 1.464, and 0.7118 million tons, respectively, which could emit much GHG to atmosphere. Therefore, Sichuan province was chosen to assess the CF of milk production in this case study. The main purposes of the study are to quantify the CFs of the milk production and to identify the contributions of individual GHG sources to total CF.

3.5.2.2   Data Source

This study involved a field survey of Hongya county, Sichuan province (103.37°E, 29.91°N) that is one of the major livestock production regions in China (Hu et al. 2010). Data collection was performed by face-to-face interviews with farmers. The obtained data included: (I) number of livestock head, (II) amounts of forage, fuel, and electricity, (III) manure treatment method and amounts of manure, and (IV) annual yield of livestock production (Table 3.18).

3.5.2.3   CF Calculation

The "farm gate" (up to harvest) was considered as the boundary of this study. Therefore, the direct emissions from enteric fermentation, manure treatment and machine operation, and indirect emissions from manufacturing of forage in milk production were considered for CF calculation up to the "farm gate" (up to harvest).

TABLE 3.18
Original Data for CF Calculation of Milk Production

Items	Data	Items	Data
Adult cow	280 heads	Cattle manure for hay production	24,841 kg
Bred cattle (>1 year)	12 heads	Electricity for irrigation	125 kw h
Calf (<1 year)	0	Gasoline for forage transport	80.416 kg
Hay	5610.78 t	Gasoline during farm management	321.66 kg
Concentrated forage	688.92 t	Electricity	23,061 kw h
Green forage	425.492 t	Milk production	1588.44 t

3.5.2.3.1   Direct Emission

3.5.2.3.1.1 CH_4 Emissions from Enteric Fermentation   In this calculation, enteric fermentation factors could be obtained from a previous study in China as shown in Table 3.19.

Hence, CH_4 emissions from enteric fermentation could be calculated as follow:

$$E_{EF} = H \times EF_{EF} \times 28 = 280 \times 86.2 \times 28 + 12 \times 61.2 \times 28 = 696,371 \quad (kg\,CO_2\text{-eq.})$$

3.5.2.3.1.2 N_2O and CH_4 Emissions by Manure Treatment   All the manure in this farm was directly applied into soil for forge cultivation. Therefore, this emission was 0 kg CO_2-eq. for this farm. The N_2O emissions by manure input are calculated in forge cultivation part.

3.5.2.3.1.3   Energy Use in Farm Management

$$E_F = \sum_i (EF_i \cdot W_i \cdot NCV_i) = 44.3 \times 69,300 \times 321.66 \times 10^{-6} = 987.49 \quad (kg\,CO_2\text{-eq.})$$

$$E_E = E \times EF_E = 23,061 \times 0.9223 = 21,269.16 \quad (kg\,CO_2\text{-eq.})$$

3.5.2.3.2   Indirect Emissions

3.5.2.3.2.1   GHG Emissions from Manufacture of Forage   As shown in Table 3.17, the forage used in this farm includes hay, concentrated forage, and green forage. The emission factors of concentrated forage and green forage production are 0.57 and 0.98 kg CO_2-eq./kg forage, respectively. However, hay was produced by themselves. The GHG emissions in the process of hay production include N_2O emissions by manure input and irrigation, which could be calculated according to CF methodology for crop production supplied by this chapter.

$$E_{N_2O} = N \times EF_{N_2O} \times \frac{44}{28} \times 265 = (24,841 \times 0.062) \times 0.02 \times \frac{44}{28} \times 265 = 12,827.18 \quad (kg\,CO_2\text{-eq.})$$

$$E_E = E \times EF_E = 125 \times 0.9223 = 115.29 \quad (kg\,CO_2\text{-eq.})$$

TABLE 3.19
Emission Factors for Enteric Fermentation of Cow

Item	Average Weight (kg)	Emission Factor (kg CH_4/head/a)
Adult cow	500	86.2
Bred cattle (>1 year)	400	61.2
Calf (<1 year)	180	39.5

Total GHG emissions by hay production are:

$$E_{Forge\_hay} = 12,827 + 115.29 = 12,942.29 \quad (\text{kg CO}_2\text{-eq.})$$

GHG emissions by all the forage input are also calculated:

$$E_{Forge} = F_C \times EF_C + F_P \times EF_P + E_T = (688,920 \times 0.57 + 425,492 \times 0.98 + 12,942.29)$$
$$+ 0 + 80.416 \times 69,300 \times 321.66 \times 10^{-6} = 824,401.4 \quad (\text{kg CO}_2\text{-eq.})$$

3.5.2.3.3　Assessment of CF of Milk Production

$$\text{CF} = E_{EF} + E_M + E_F + E_E + E_{labor} + E_{Forage} = 696,371 + 0 + 987.49 + 21,269.16 + 814,401.4$$
$$= 1,533,029.05 \quad (\text{kg CO}_2\text{-eq.})$$

CF of milk production in terms of production is calculated below:

$$CF_P = \frac{CF}{P} = \frac{1,533,029.05}{1,588,440} = 0.97 \quad (\text{kg CO}_2\text{-eq./kg milk produced})$$

3.5.2.4　Results

According to this calculation, the CF of milk production in this farm is 0.97 kg CO_2-eq./kg milk produced. Proportions of GHG emissions by different inputs in CF were calculated to assess the contribution of each emission source to the total CF (Figure 3.3). For milk production, forage input **Q2** contributed the most GHG emission in the total CF (53%), and the contributions of enteric fermentation was 45%. Emissions in the process of farm management made a contribution as small as 2%.

3.5.2.5　Sensitivity Analysis

The sensitivity of the total CF to different inputs and milk yield was further evaluated in this study, including CH_4 emissions from enteric fermentation, energy use in farm management, GHG emissions from manufacture of forage and milk yield, respectively. As shown in Table 3.20, the
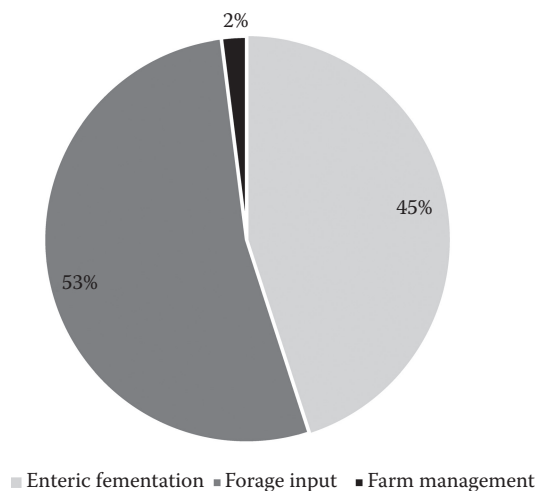

■ Enteric fementation　■ Forage input　■ Farm management

FIGURE 3.3　Contributions of agricultural inputs to total CF of milk production.

TABLE 3.20

Sensitivity Analysis of Various Agricultural Inputs and Milk Yield to Total CF in Milk Production (in %)

Item	−10%	10%
CH_4 emissions from enteric fermentation	−4.51	4.51
Energy use in farm management	−0.14	0.14
GHG emissions from manufacture of forage	−5.34	5.34
Yield	9.09	−9.09

calculated CF responded differently to changes in the different parameters. The most sensitive parameters were milk yield (9.09 and −9.09% for 10% decrement and increment, respectively), GHG emissions from manufacture of forage (−5.34 and 5.34% for 10% decrement and increment, respectively), and CH_4 emissions from enteric fermentation (−4.51 and 4.51% for 10% decrement and increment, respectively). The sensitivity of energy use in farm management in farm management had a much smaller influence on CF in our evaluation. Sensitivity analysis gave us a suggestion that the reliability of data sources of these inputs is a key factor to obtain the accurate CF results. These also indicated that the increase of milk production and forage use efficiency and decrease of CH_4 emissions from enteric fermentation could be a strategy to reduce CF in milk production.

3.5.2.6 Conclusions

This case study quantified the CF of milk production in Sichuan province of China using data from questionnaire survey. GHG emissions from enteric fermentation and forage use contributed significantly to the total CF.

3.5.3 Limitations and Recommendations

As a basic assessment of CF of crop and livestock production, there would be still an issue of uncertainty. As an estimation for regional CF of crop production, the direct N_2O emission from N fertilizer use was estimated using default value by IPCC (2006). In addition, emissions from fertilizers of potassium and phosphorus and from use of pesticides were estimated using those reported by Dubey and Lal (2009). Other factors such as CO_2 emission from N fertilizer and plastic film manufacturing, as well as irrigation energy consumption were estimated from synthesizing data available from Chinese literature though limited. The selection of emission factors may cause some uncertainties in the CF calculation. Hence, the development of region-specific emission factors is one of key assignments for further studies. There could be some uncertainties induced by data collection, especially by field survey. In the second case study, we chose a farm in Sichuan province as a sample to calculate the CF of milk production. However, there may be some biases or errors for the data obtained from field survey due to the survey approaches and the knowledge of farmers. Therefore, the reasonable approach of field survey such as the design of survey forms and the selection of farm samples is very important for further studies, and increasing the number of samples may lower the uncertainties of the estimates.

We have not considered the impact of soil carbon balance on farm gate emissions in the first case study, because there were limited data concerned on soil carbon balance in a given crop production in Shandong province. The soil forms a large C pool, and there is thus scope for large amounts of C to be gained or lost from soils as a consequence of farming practice. For example, Lal (2004) reported management of repeated disturbance has turned many arable soils into C sources. But, some studies showed that the C sequestration in soil had not changed in conventional till, while reducing tillage or no till would lead to C sequestration in the soil (Smith et al. 2008). Soil carbon

balance should be taken into account when CFs are estimated under different agricultural management related to carbon balance in further studies.

ACKNOWLEDGMENTS

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