

# Comparison of Carbon Footprint of Organic and Conventional Farming of Chinese Kale

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## ABSTRACT

This study compared the carbon footprint (CF) of organic agriculture with that of conventional agriculture in the cultivation of Chinese kale. The farm management data collected included the use of chemical and organic fertilizers, and fossil fuel for tillage, irrigation and transportation. Greenhouse gas emissions (GHG) were calculated and added to the CF. The results showed that conventional agriculture had a CF of  $0.402 \pm 0.47$  kg CO<sub>2</sub>e/kg Chinese kale. Proportion of CFs from: chemical fertilizer (51%), transportation (21%), irrigation (19%), tillage (5%), organic fertilizer (2%), herbicide (1%) and insecticide (1%), and organic agriculture had a CF of  $0.195 \pm 0.122$  kg carbon dioxide CO<sub>2</sub>e/kg Chinese kale (proportion of CFs from: transportation (81%) organic fertilizer (12%) and fossil fuel for irrigation (7%). The CFs differed, depending on farm management, and that of conventional agriculture was almost double that of organic agriculture because of the higher emissions from use of chemical fertilizers and of fossil fuel for tillage, herbicide and insecticide applications. The conventional farm management led to higher production per unit of planted area. Thus, it seems that conventional farming has relatively higher CF than organic farming. There is still room for both management practices to reduce their GHG emissions and their CFs by reduce chemical fertilizer and fossil fuel use in conventional farming. The promotion of organic farming practices will help to improve sustainable, environmentally friendly agricultural production of Chinese kale in Thailand.

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## 1. INTRODUCTION

Agriculture has a complex relationship with global warming, by theses; Chinese kale is one of the important food crops in Thailand. Thailand is an agricultural-based country and agriculture contributed about 21% of its total greenhouse gas (GHG) emissions in 2000 (51 Mt carbon dioxide (CO<sub>2</sub>e) (The Joint Graduated School of Energy and Environment, 2009). Emissions are influenced by cultivation practices and processes throughout agricultural production and product use. Organic farming began in Thailand to lower the high production costs for agriculture (chemical fertilizers, herbicides, insecticides) and reduce the chemical residues in products that caused problems for the food web and human health. To reduce production costs and maintain a good environment, the Thai government aimed to promote organic farming with a “Sufficiency Economy Concept” (SE), a philosophy initiated by King Bhumipol Adulyadej (King Rama IV of Thailand) that advocates moderation, self-sufficiency and reasonable consumption patterns to Thai farmers and the

general populous”. This involved the government transferring knowledge to and supporting a philosopher who was known to practice good organic farming and acted as a role model, motivating other farmers and interested members of the general public. Thus, it could improve conservation by applying this knowledge to sustainable agriculture (Ministry of Agriculture and Cooperatives, 2010). In addition, a philosopher knowledgeable about organic farming could extend that knowledge to other communities. Thus, organic farming could reduce production costs in general, while also being environmentally friendly in terms of carbon footprint (CF) by reducing GHG emissions.

For example, a previous study reported sustainable agriculture methods in the sustainable cultivation of Thai Hom Mali (Jasmine) rice in Thailand. The study had statistical samples from the most intensive cultivation provinces, such as Phayao (Northern region), Sisaket (Northeastern), Chachoengsao (Central region) and Nakhonsi-thammarat (Southern region). Two indicators were

assigned to assess the sustainable cultivation of Thai farmers, designated as Sustainability in Cultivation Practices (SCP), and the Composite Sustainability Indicators (CSI). The findings revealed that the northeastern region had the highest values of SCP and a higher level of CSI than other regions of Thailand. Besides the independent variables of SCP, in particularly production costs, chemical and fertilizer utilization, the risk of weeds and pests were found to be the significantly common variables in most of the regions of Thai Hom Mali (Jasmine) rice cultivation environment. A sustainability Index and some indicators were adopted for SA (Sustainable agriculture), such as the Framework for the Evaluation of Sustainable Land Management, Land Quality Indicators, and Environmental Sustainability Index for agricultural systems. There are additional indicators for sustainable cultivation designated non chemical fungicide use, non-chemical insecticide use and non-chemical herbicide use. These are promoted options to farmers to have sustainable cultivation in Thailand by organic farming (Chaimanuskul et al., 2011).

In addition, several studies have reported and linked to sustainable agriculture in Thailand. In one organic farmers program, non-governmental organizations have assisted farmers. This research examined the socio-ecological benefits of organic production to rice farmers by using semi-structured interviews with 50 farmers in northeastern Thailand. These Thai organic farmers shed light on shared values, perceptions, and actions towards nature. In another study, 75 members of organic farmer groups investigated the ways that informants improved soil fertility. Organic farmers perceived bountiful rice and good health as externalities of nurturing the soil. By engaging in organic fertilizer practices respondents came to see themselves as part of an extended community of life. Data analysis reveals that participation in fertilizer groups contributes to improved health, wellbeing, and the long-term sustainability of organic farms. A better environment and good health are given by organic farming (Kaufman et al., 2011). The development of organic rice as a niche experiment was partly due to landscape changes but also due to NGOs, farmers and academic leaders, often as a reaction to the negative impacts of agrochemical-based commercial rice. A previously reported in-depth study found that if intensive promotion is applied, organic rice could

become quite successful in terms of production and marketing (Kerdnoi et al., 2014).

A previous study reported that the concept of organic farming and sufficiency economy can help to reduce GHG emissions from agricultural activities and improve soil fertility and the soil carbon stock (Chaimanuskul et al., 2011; Kaufman et al., 2011; Thailand Research Fund, 2010). The latter study also reported the CF of organic and conventional farming and showed that organic farming had a lower CF than conventional farming. The comparisons between GHG emissions from coffee cultivation in Costa Rica show that the reported organic farming CF was 0.12-0.52 kg CO<sub>2</sub>e/kg fresh coffee and the reported conventional farming CF was 0.26-0.67 kg CO<sub>2</sub>e/kg fresh coffee. The difference in CF between these two systems was represented by nitrogen chemical fertilizer use. Energy use from organic farming was lower than in conventional farming (Dalgaard et al., 2001; Meisterling et al., 2009; Kaltasas et al., 2007). Moreover the life cycle assessment (LCA) and CF concept was a good concept for response to consumers who are environmental friendly. Estimates of CF is not only useful for agriculture products but also other products, for example; aquatic product (shrimp), green logistic systems, biodiesel etc. (Mungkung et al., 2012; Prapasongsa et al., 2012; Rewlay-Ngoen et al., 2013). Levels of GHG emissions in terms of CF can be estimated from such crop systems, but emissions from organic farming in Thailand are less well known.

In this study, the CF of Chinese kale was chosen because of increasing demand and more widespread use of this product as food. Normal cultivation practice for Chinese kale involves large amounts of chemical fertilizer, herbicide and insecticide to control weeds and pests. This paper presents the findings of a study whose objective was to evaluate the CF of organic and conventional farming of Chinese kale. We expect that the results of this study can be used to promote the policy of organic farming in other areas of Thailand. Organic production allows farmers to be more competitive and market-oriented, to keep their land in good agricultural and environmental condition, and to ensure food safety and animal health and welfare. The life cycle assessment (LCA) concept can be the basis for assessing the environmental sustainability of organic agriculture, and for identifying options

aimed at improving the global environmental performance of agricultural products.

## 2. METHODOLOGY

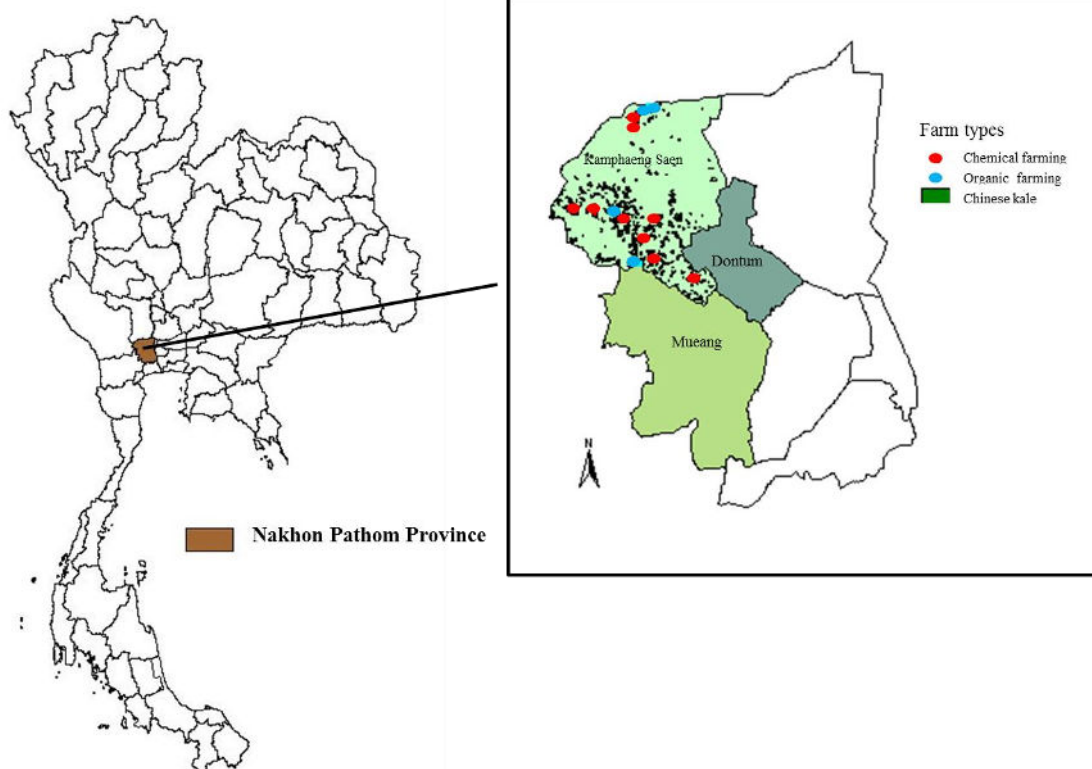
### 2.1 Description of sites and data collection

This study estimated emissions from conventional and organic farming of Chinese kale. The study site was located on an experimental farm in Kamphaeng Saen, Mueang and Don Tum district, Nakhon Pathom province, Thailand (Figure 1). Chinese kale in all areas of Thailand covered 5,134.88 ha; production was 1,900 tons; and the average yield was 10.08 kg/ha (Office of Agricultural Economics, 2015). Statistics show that western Thailand had the highest production. In addition, Nakhon Pathom province had the highest number of households that planted Chinese kale.

Data were collected from 518.08 ha of Chinese

kale planting area in the 2015 production year, or about 10.09% of the total planting area in Thailand (Figure 1).

The following are the cultivation practices commonly applied to the Chinese kale field in this region, which served as the basis for estimating CFP in this study: Chinese kale is planted 2-3 times per year and the harvest takes place 45-55 days after planting. Plowing of the fields are carried out. Organic fertilizer is usually applied before planting. Chemical fertilizer is applied only once as a composite fertilizer and urea (chemical fertilizer was applied in conventional farming). In addition, if irrigation water is needed, it is usually pumped from nearby ponds just prior to planting and 2-3 days after planting periods. Herbicide and insecticide are usually applied to control weeds and insects (Table 1 and Table 2).



**Figure 1.** Chinese kale area located in Nakhon Pathom province, Thailand

### 2.2 LCA approach

#### 2.2.1 System boundaries

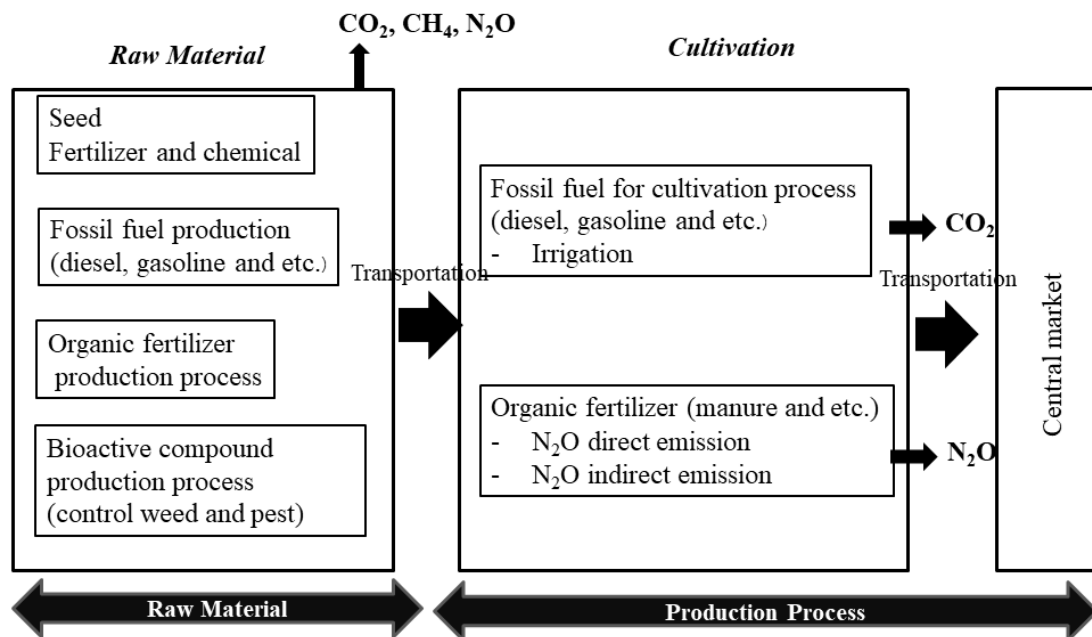
We analyzed the global warming potential (GWP) from the CF of two different boundaries: organic and conventional farming practice. The CF was estimated following the life cycle assessment (LCA) concept and Publicly Available Specification

(PAS) 2050 method (The British Standards Institution, 2008; Sinden, 2009). Four stages of the life cycle of Chinese kale (cultivation, production, processing and transportation) were considered. The systems boundary covered GHG emissions from raw materials used in Chinese kale cultivation (Figure 2). The system boundaries were used in a Business-to-

Business (B2B) or Cradle to Gate approach and covered GHG emissions from raw material use for cultivation and production (Figure 2 and Figure 3). The study boundaries of both systems included all production steps from field to farm gate including machinery production and use, fossil fuel use for farm operations, inputs (fertilizers, herbicides, insecticides and seed), water use and transportation of the produce to the central market.

In general, the system boundary of organic farming included irrigation, application of bio-active

herbicides and insecticides, the production process and organic fertilizer application (Figure 2). Organic farming processes try to reduce the use of chemical substrates. Conventional farming is different: most conventional farming uses chemical substances including fertilizer, herbicide and insecticide. The system boundary of conventional farming includes tillage, irrigation, herbicide and insecticide application, chemical fertilizer and organic fertilizer use (Figure 3).



**Figure 2.** System boundary of organic farming

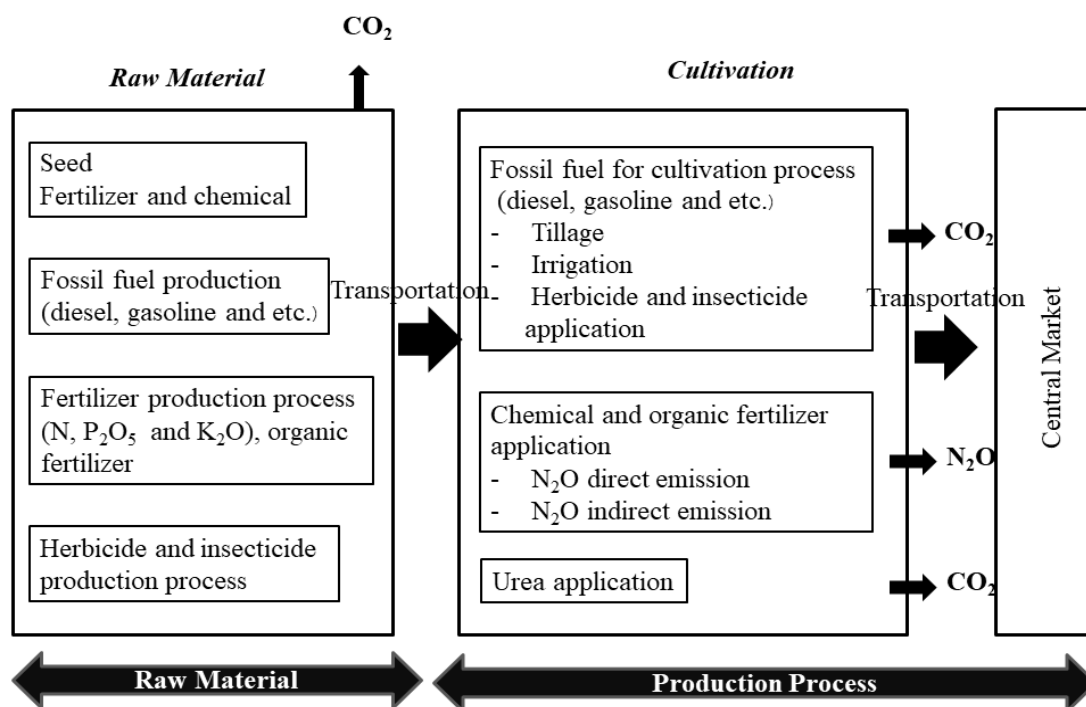
### 2.2.2 Functional unit

The functional unit (FU) was defined as kg CO<sub>2</sub>e/kg of Chinese kale. These were compared between two system boundary from organic and conventional as mentioned above. The scope and goals were defined to record the data from the input and output of the cultivation process, estimating the CF from fresh Chinese kale. It assumed that the boundary of production extended from the farm to the central market. The GHGs to be estimated were CO<sub>2</sub>, methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Each gas was converted into its CO<sub>2</sub> equivalent by use of GWP equivalent factors. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O have a GWP of 1, 25 and 298, respectively. These values

came from the latest IPCC 100-year time horizon of GWP equivalent factors (IPCC, 2007).

### 2.2.3 Life cycle inventory

The inventory analysis quantified the environmentally significant inputs and outputs of the systems examined, by means of the mass and energy balances of the selected FU of the study. The main energy and materials input and output of the Chinese kale supply chain were collected from the experimental farm (Figure 1) according to the information provided by farmers collected by using questionnaires. The data show the main inputs and outputs involved in organic (Table 1) and conventional farming (Table 2).



**Figure 3.** System boundary of conventional farming

**Table 1.** Data input; planted area, yield, the quantity of fertilizer application, fossil fuel use, seed, cultivation method from organic farming

Details	Organic farming
Harvested time (day)	45-55
Seed (kg/ha)	3.13
Planted area (ha)	12.5-31.25
Planted period in this area (year)	1-2
Crop rotation (crop/year)	2
Yield (ton/ha)	10
Product price (USD/kg) <sup>b</sup>	0.43-0.57
Diesel for tillage practice (L/ha)	–
Tillage time (time/crop)	–
Number of fertilizer application	1-2
Quantity of nitrogen in chemical fertilizer (kg/ha)	–
Quantity of nitrogen in organic fertilizer (kg/ha)	4.75
Urea (46-0-0) (kg/ha)	–
Organic fertilizer (kg/ha)	625-3,125
Type of bioactive compound to control weed and pest	Pyroligneous acid, Buvaria, Effective microorganisms(EM)
Quantity of herbicide and insecticide (cc/ha)	–
Type of weed control	Man power
Quantity of weed control (cc/ha)	–
Gasoline for machinery to spray herbicide and insecticide (L/ha)	–
Gasoline for machinery to spray chemical to control weed (L/ha)	–
Diesel for irrigation system (L/ha)	–
Price of electricity for irrigation system (USD/ha) <sup>b</sup>	35.71
Water resource	Natural pond

**Table 1.** Data input; planted area, yield, the quantity of fertilizer application, fossil fuel use, seed, cultivation method from organic farming (cont.)

Details	Organic farming
Quantity of nitrogen in organic fertilizer (chicken manure) (%/W) <sup>a</sup>	1.2-4.9
Quantity of nitrogen in organic fertilizer (cow manure) (%/W) <sup>a</sup>	0.32-1.2
Distance to central market (two way) (km)	24-30 Mueang district, Nakhon Pathom province
Fossil fuel use for transportation (L/km)	24

<sup>a</sup>Suwanarit, 2010<sup>b</sup>Exchange rate: 1 USD ~ 35 baht**Table 2.** Data input; planted area, yield, the quantity of fertilizer application, fossil fuel use, seed, cultivation method from conventional farming

Details	Conventional farming
Harvested time (day)	45-55
Seed (kg/ha)	3.13
Planted area (ha)	12.5-62.5
Planted period in this area (year)	3-30
Crop rotation (crop/year)	2-5
Yield (ton/ha)	12.5-31.25
Product price (USD/kg) <sup>b</sup>	0.057-0.114
Diesel for tillage practice (L/ha)	50-93.75
Tillage time (time/crop)	1-3
Number of fertilizer application	1-3
Quantity of nitrogen in chemical fertilizer (kg/ha)	250-625
Quantity of nitrogen in organic fertilizer (kg/ha)	
Urea (46-0-0) (kg/ha)	62.5-1,250
Organic fertilizer (kg/ha)	312.5-1,875
Type of bioactive compound or chemical compound to control weed and pest	Buakum, Hachi Hachi, Simtrack, Abamethene
Quantity of herbicide and insecticide (cc/ha)	3,125-6,250
Type of weed control	Gramoxone, Rampat, Glyphosate
Quantity of weed control (cc/ha)	3,750-6,250
Gasoline for machinery to spray herbicide and insecticide (L/ha)	3.13-62.5
Gasoline for machinery to spray chemical to control weed (L/ha)	3.13-25
Diesel for irrigation system (L/ha)	143.75-518.75
Price of electricity for irrigation system (USD/ha) <sup>b</sup>	35.71
Water resource	Natural pond
Quantity of nitrogen in organic fertilizer (chicken manure) (%/W) <sup>a</sup>	1.2-4.9
Quantity of nitrogen in organic fertilizer (cow manure) (%/W) <sup>a</sup>	0.32-1.2
Distance to central market (two way) (km)	200 Talad Thai market, Patum Thani province
Fossil fuel use for transportation (L/km)	68

<sup>a</sup>Suwanarit, 2010<sup>b</sup>Exchange rate: 1 USD ~ 35 baht

### 2.2.4 Estimation of CF from organic and conventional farming

GHG emissions were calculated from the production and application of fertilizers, herbicides and insecticides, and of fossil fuel use, during the two methods of cultivation. This study aimed to compare emissions from different farming methods (organic and conventional farming). The system boundaries were drawn at the farm gate and included raw materials used in cultivation (Figure 2 and Figure 3). Information was obtained from the interviews of Chinese kale farmers (4 farms of organic farming and 11 farms of conventional farming). The study site was located on an experimental farm in Kamphaeng Saen, Mueang and Don Tum district, Nakhon Pathom province, Thailand as mention above. The distance between farms was approximated 1-30 kilometers (Figure 1). Moreover, both chemical and organic fertilizers were

applied. The application amount was obtained from interviews of Chinese kale farmers for the whole period of Chinese kale planting. We used 0.01 kg-N N<sub>2</sub>O/kg N applied to estimate N<sub>2</sub>O from direct nitrogen fertilizer application. Indirect N<sub>2</sub>O emissions from atmospheric deposition, leaching and runoff were also estimated. CO<sub>2</sub> emissions from the use of urea were accounted for using the emission Intergovernmental Panel on Climate Change (IPCC) factors (IPCC, 2006). Information on energy use for farm operations and management was obtained from the questionnaires. The energy types included gasoline and diesel for herbicide and insecticide application, tillage, irrigation and transportation of product to the central market. The emissions were estimated from the amount of fuel used and the emission factors listed in Table 3. Finally, the calculation was based on the IPCC method (IPCC, 2006).

**Table 3.** Emission factors use for calculation of greenhouse gases emissions from Chinese kale cultivation from organic and conventional farming

Activity	Emission factors	Unit
<i>Production (Raw material)</i>		
Production of diesel <sup>c</sup>	0.3282	kg CO <sub>2</sub> e/kg
Production of gasoline <sup>c</sup>	0.7069	kg CO <sub>2</sub> e/kg
Production of diesel (low S) <sup>a</sup>	0.4293	kg CO <sub>2</sub> e/L
Production of gasoline (unleaded) <sup>a</sup>	0.5093	kg CO <sub>2</sub> e/L
Production of N <sup>c</sup>	3.3036	kg CO <sub>2</sub> e/kg
Production of P <sub>2</sub> O <sub>5</sub> <sup>c</sup>	1.5716	kg CO <sub>2</sub> e/kg
Production of K <sub>2</sub> O <sup>c</sup>	0.4974	kg CO <sub>2</sub> e/kg
Production of Urea-Production <sup>c</sup>	3.2826	kg CO <sub>2</sub> e/kg
Urea (include N <sub>2</sub> O) (production + utilization) <sup>c</sup>	5.5300	kg CO <sub>2</sub> e/kg
Organic fertilizer (dry chicken manure)-production <sup>c</sup>	0.1097	kg CO <sub>2</sub> e/kg
Electricity, grid mix (electricity) <sup>c</sup>	0.6093	kg CO <sub>2</sub> e/kWh
Natural gas <sup>c</sup>	0.1515	kg CO <sub>2</sub> e/kg
LPG <sup>c</sup>	0.4232	kg CO <sub>2</sub> e/kg
Glyphosate <sup>c</sup>	16.000	kg CO <sub>2</sub> e/kg
Atrazine <sup>c</sup>	5.0100	kg CO <sub>2</sub> e/kg
Alachlor <sup>c</sup>	8.0900	kg CO <sub>2</sub> e/kg
Paraquat <sup>c</sup>	3.2300	kg CO <sub>2</sub> e/kg
Bromacil <sup>c</sup>	5.2500	kg CO <sub>2</sub> e/kg
Diuron <sup>c</sup>	7.0400	kg CO <sub>2</sub> e/kg
Ametine <sup>c</sup>	8.5100	kg CO <sub>2</sub> e/kg
<i>Utilization (Emission from utilization)</i>		
Diesel-combustion <sup>b</sup>	2.7080	kg CO <sub>2</sub> e/L
Gasoline-combustion <sup>b</sup>	2.1896	kg CO <sub>2</sub> e/L

**Table 3.** Emission factors use for calculation of greenhouse gases emissions from Chinese kale cultivation from organic and conventional farming (cont.)

Activity	Emission factors	Unit
Electricity utilization <sup>d</sup> : CO <sub>2</sub>	0.0564	kg CO <sub>2</sub> e/MJ
CH <sub>4</sub>	1	kg CH <sub>4</sub> /TJ
N <sub>2</sub> O	0.1	kg N <sub>2</sub> O/TJ
N <sub>2</sub> O direct emission from fertilizer use <sup>d</sup>	0.01	kg N <sub>2</sub> O-N/ kg N-input
N <sub>2</sub> O direct emission from fertilizer after N leaching and runoff <sup>d</sup>	0.0075	kg N <sub>2</sub> O-N (kg leaching per runoff)
N <sub>2</sub> O indirect emission after emission of fertilizer N as NO <sub>x</sub> and NH <sub>3</sub> <sup>d</sup>	0.01	kg N <sub>2</sub> O-N (kg of N applied per kg NH <sub>3</sub> -N + NO <sub>x</sub> -N)
Urea <sup>c</sup>	2.2474	kg CO <sub>2</sub> e/kg
The nutrient from organic fertilizer (cow manure) <sup>e</sup> % by Weight;		
N	0.32-1.2	%/W
P	0.21-0.39	%/W
K	0.16-3.10	%/W
The nutrient from organic fertilizer (chicken manure) <sup>e</sup> % by Weight;		
N	1.2-4.9	%/W
P	0.7-4.1	%/W
K	0.47-3.50	%/W

<sup>a</sup>Thailand National Technical Committee on Product Carbon Footprint, 2009

<sup>b</sup>Thailand National Technical Committee on Product Carbon Footprint, 2011

<sup>c</sup>Thailand National Technical Committee on Product Carbon Footprint, 2015

<sup>d</sup>IPCC, 2006

<sup>e</sup>Suwannarit, 2010

### 2.2.5 The calculation of greenhouse gas emissions

Greenhouse gas emissions were calculated in every step by multiplying the emission factor of the material by the energy of that process (Equation 1) and recorded in terms of greenhouse gas emissions per unit of product.

$$\text{CO}_2 \text{ Emission} = \text{Activity data} \times \text{Emission factor} \quad (1)$$

where the activity data is energy used in each step such as raw materials (tons), and emission factor is the coefficient of pollutant emissions.

If the greenhouse gases were other gases, their emission was adjusted to a carbon dioxide equivalent by using GWP (Equation 2).

$$\text{CO}_2 \text{ Emission} = \text{Emission} \times \text{GWP} \quad (2)$$

where GWP is potential of global warming in term of carbon dioxide equivalent (CO<sub>2</sub>=1, CH<sub>4</sub>=25 and N<sub>2</sub>O=298) (IPCC, 2007).

The N<sub>2</sub>O Emissions from synthetic fertilizer and manure application-direct emission. N<sub>2</sub>O Emissions from N fertilizer utilization was represented in Equation 3 (IPCC, 2006).

$$\text{N}_2\text{O}-\text{NN}_{\text{input}} = \text{F}_{\text{SN}} + \text{F}_{\text{ON}} \times \text{EF}_1 \quad (3)$$

where N<sub>2</sub>O-NN<sub>inputs</sub> is annual direct N<sub>2</sub>O-N emissions from N inputs to manage soils (kg N<sub>2</sub>O-N/year). F<sub>SN</sub> is annual amount of synthetic fertilizer N applied to soils (kg N/year). F<sub>ON</sub> is annual amount of manure applied to soils (kg N/year). EF<sub>1</sub> is emission factor for N<sub>2</sub>O emissions from N inputs (kg N<sub>2</sub>O-N /kg N input). This is 0.01 kg N<sub>2</sub>O-N/kg N input (IPCC, 2006)



N<sub>2</sub>O Emissions from atmospheric deposition of N volatilized from managed soil were represented in Equation 4. The equation for this purpose is given below (IPCC, 2006).

$$N_2O_{(ATD)-N} = [(F_{SN} \times \text{Frac}_{GASF}) + (F_{ON} + F_{PRP} \times \text{Frac}_{GASM})] \times EF_4 \quad (4)$$

where N<sub>2</sub>O<sub>(ATD)-N</sub> is annual amount of N<sub>2</sub>O-N produced from atmospheric deposition of N volatilized from managed soils, kg N<sub>2</sub>O-N/year. F<sub>SN</sub> is annual amount of synthetic fertilizer N applied to soils, kg N/year. Frac<sub>GASF</sub> is fraction of synthetic fertilizer N that volatilizes as NH<sub>3</sub> and NO<sub>x</sub>, kg N volatilized (kg of N applied)<sup>-1</sup>; 0.10 kg NH<sub>3</sub>-N + NO<sub>x</sub>-N (IPCC, 2006). F<sub>ON</sub> is annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N/y. F<sub>PRP</sub> is annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N/year. Frac<sub>GASM</sub> is fraction of applied organic N fertilizer materials (F<sub>ON</sub>) and of urine and dung N deposited by grazing animals (F<sub>PRP</sub>) that volatilizes as NH<sub>3</sub> and NO<sub>x</sub>, kg N volatilized (kg of N applied or deposited)<sup>-1</sup>; 0.20 kg NH<sub>3</sub>-N + NO<sub>x</sub>-N (IPCC, 2006). EF<sub>4</sub> is emission factor for N<sub>2</sub>O emissions from atmospheric deposition of N on soils and water surfaces, [kg N-N<sub>2</sub>O/(kg NH<sub>3</sub>-N + NO<sub>x</sub>-N volatilized)]; 0.010 kg N<sub>2</sub>O-N (IPCC, 2006)

N<sub>2</sub>O Emissions from N fertilizer utilization and manure by leaching and runoff were estimated according to the methodology of IPCC (2006) and were represented in Equation 5. The equation for this purpose is given below (IPCC, 2006).

$$N_2O_{(L)-N} = (F_{SN} + F_{ON}) \times \text{Frac}_{LEACH-(H)} \times EF_5 \quad (5)$$

where N<sub>2</sub>O<sub>(L)-N</sub> is annual amount of N<sub>2</sub>O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N<sub>2</sub>O-N/year. F<sub>SN</sub> is annual amount of synthetic fertilizer N applied to soils in regions where leaching/runoff occurs, kg N/year. F<sub>ON</sub> is annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N/year. Frac<sub>LEACH-(H)</sub> is fraction of all N added to/mineralized in managed soils in regions where leaching/runoff=0.30. EF<sub>5</sub> is emission factor for N<sub>2</sub>O emissions from N leaching and runoff, kg N<sub>2</sub>O-N

(kg N leached and runoff)<sup>-1</sup> (TabIPCC 2006)=0.0075 kg N<sub>2</sub>O-N (kg leaching/runoff). All emission factors and data use for calculation were listed in Tables 1-3.

### 3. RESULTS AND DISCUSSION

#### 3.1 Input, yields and emissions from crop management

##### 3.1.1 Characteristics of Chinese kale production in Nakhon Pathom province

Agricultural practices in organic and conventional Chinese kale production during the study period are shown in Table 1 and Table 2. Calculation of GHG emissions by the crop was based on the farmer's work schedule, the time taken for each operation, the number of labourers and machines, and all inputs used for field operations (fertilizer applications, insect trapping, etc.). To calculate CF from this activity, we recorded the use of materials and fuel consumption, as well as the time needed to complete each operation (Table 3). The differences between the two practices were the amounts of fertilizer, herbicide and insecticide applied; the type of chemical and methodology to control weeds and pests; energy and fossil fuel use; markets; product price; and the quantity of product (Table 1 and Table 2).

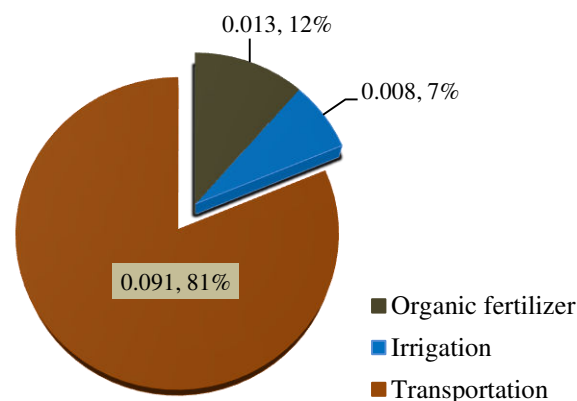
Information on chemical farming, the general features of farms, farm operations and energy utilization from 11 questionnaires (or farms) shows a wide range of the amount of resource inputs (Table 2). The yield per hectares range was 12.5-31.25 tons/ha. From the interviews, most of the farmers have continued growing their Chinese kale for 3-30 years. Thus, the emissions from land used changed to Chinese kale was not accounted for in this study. Chinese kale yield was sent to Talad Thai market located in Patum Thani province, Thailand. On average, the farms were located about 200 km from the market. Average diesel consumption was 50-3.75 L/ha. It is worth noting that the N fertilizer application rate range was 250-625 kg/ha, urea was 62.5-1,250 kg/ha and organic fertilizer was 312.5-1,875 kg/ha. Irrigation was usually carried out during the start of the growing season and 2-3 days after Chinese kale planting. Energies required for trucks and pumps to spray water were diesel and gasoline. Herbicide and insecticide was applied by the type of bioactive and chemical compound to control weed and pest (Buakum, Hachi Hahi, Simtrack and Abamethene etc.) (Table 2).

The general features of organic farms differed from farms that used chemical fertilizer. Responses about energy utilization from 4 questionnaires (or farms) show a wide range of resource inputs (Table 1). The yield per hectares range was 10 tons/ha. From the interviews, the farmers have grown their Chinese kale for 1-2 years. Chinese kale yield was sent to the market located within Nakom Pathom province, Thailand. On average, the farms were located about 24-30 km from the market. The organic fertilizer was applied at 625-3,175 kg/ha. Irrigation was similar with chemical farming. Bioactive compounds (Pyroligneous acid, Buvaria and Effective microorganisms (EM)) were used as herbicide and insecticide to control weeds and pests (Table 1).

### 3.2 CF from organic farming (raw material, cultivation and transportation to central market)

The CF of organic farming included emissions from fossil fuel for irrigation and fertilizer as represented by the unit of kg CO<sub>2</sub>e/kg of Chinese

kale. The number of CF was 0.195±0.122 kg CO<sub>2</sub>e/kg of Chinese kale (N=4) (Table 4 and Figure 4). The highest emissions came from transportation (0.091 kg CO<sub>2</sub>e/kg of fresh product, 81%) followed by organic fertilizer (0.113 kg CO<sub>2</sub>e/kg of Chinese kale, 12%) and fossil fuel for irrigation (0.008 kg CO<sub>2</sub>e/kg of Chinese kale, 7%), respectively (Figure 4).



**Figure 4.** The proportion of emission from organic farming (kg CO<sub>2</sub>e/kg of Chinese kale)

**Table 4.** Carbon footprint of organic Chinese kale (including emission from raw material, utilization, cultivation and transportation)

No.	Emission sources kg CO <sub>2</sub> e/ha			Total emission	Total emission (kg CO <sub>2</sub> e/kg of Chinese kale)
	Organic fertilizer <sup>a</sup>	Irrigation <sup>b</sup>	Transportation <sup>c</sup>		
1	1,598.19	441.5	1,180.25	3,219.88	0.322
2	360.75	441.5	944.19	1,746.44	0.175
3	239.81	110.38	Planting for household	350.19	0.035
4	1,082.31	331.13	1,062.19	2,475.63	0.248
Mean	820.27	331.13	1,062.21	1,948.04	0.195
S.D.	638.21	156.09	118.03	1,223.34	0.122

<sup>a</sup>Organic fertilizer utilization (direct and indirect N<sub>2</sub>O emission) and organic fertilizer production

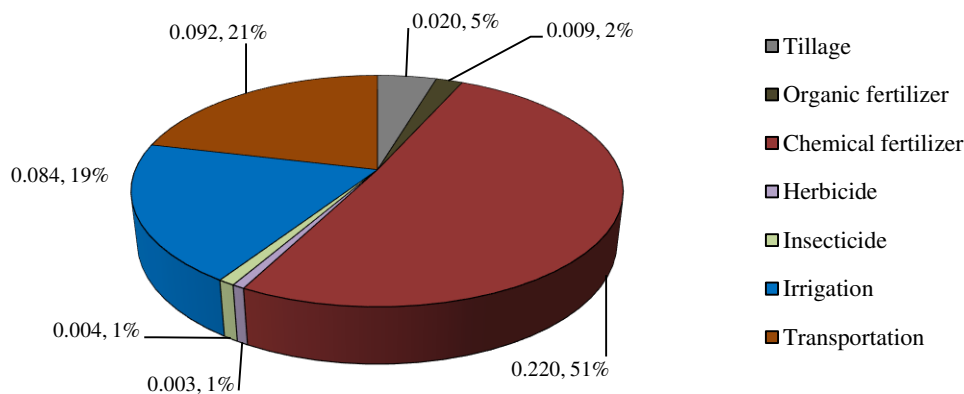
<sup>b</sup>Energy for irrigation system; fossil fuel and electricity (utilization and production)

<sup>c</sup>Energy for transportation of product to central market (utilization and production)

### 3.3 CF from conventional farming (raw material, cultivation practice and transportation to central market)

The CF of conventional farming included the emissions from tillage, organic and chemical fertilizer, herbicides, insecticides, irrigation and transportation. The total emission was 0.402±0.47 kg CO<sub>2</sub>e/kg of Chinese kale (N=11) (Table 5). The highest emission came from chemical fertilizer (0.22

kg CO<sub>2</sub>e/kg of Chinese kale, 51%) followed by transportation (0.092 kg CO<sub>2</sub>e/kg of Chinese kale, 21%), irrigation (0.084 kg CO<sub>2</sub>e/kg of Chinese kale, 19%), tillage (0.020 kg CO<sub>2</sub>e/kg of Chinese kale, 5%), organic fertilizer (0.009 kg CO<sub>2</sub>e/kg of Chinese kale, 2%), herbicide (0.004 kg CO<sub>2</sub>e/kg of Chinese kale, 1%) and insecticide (0.003 kg CO<sub>2</sub>e/kg of Chinese kale, 1%) (Table 5 and Figure 5).



**Figure 5.** The proportion of emission from conventional farming (kg CO<sub>2</sub>e/kg of Chinese kale)

**Table 5.** Carbon footprint of conventional farming (including emission from raw material, utilization, cultivation and transportation)

No.	Emission sources kg CO <sub>2</sub> e /ha							Total	Total emission (kg CO <sub>2</sub> e/kg of Chinese kale)
	Tillage <sup>a</sup>	Organic Fertilizer <sup>b</sup>	Chemical fertilizer <sup>c</sup>	Insecticide <sup>d</sup>	Herbicide <sup>e</sup>	Irrigation <sup>f</sup>	Transportation <sup>g</sup>		
1	294.13	-	988.00	135.97	-	882.38	1,290.38	3,590.63	0.287
2	294.13	59.31	1476.00	54.40	72.53	441.19	1,290.38	3,687.69	0.197
3	176.50	243.38	885.63	16.78	45.37	1,617.69	1,290.38	4,275.56	0.342
4	294.13	-	2,180.00	18.15	-	1,307.25	1,290.38	5,089.94	0.204
5	294.13	-	8,206.50	-	9.07	1,307.25	1,290.38	11,107.31	1.777
6	294.13	-	2,952.00	181.35	72.53	1,176.50	1,290.38	5,966.44	0.318
7	294.13	-	5,470.19	38.19	116.59	1,176.50	1,290.38	8,385.69	0.447
8	294.13	59.31	1,095.88	19.09	116.59	1,176.50	1,290.38	4,051.69	0.216
9	294.13	-	662.13	2.00	18.15	-	1,290.38	2,266.69	0.121
10	294.13	-	1,366.94	12.08	89.86	-	1,290.38	3,053.25	0.326
11	294.13	-	1,848.81	19.09	89.86	-	1,290.38	3,542.13	0.189
Mean	283.43	120.67	2,466.55	45.19	70.06	1,135.66	1,290.38	5,001.55	0.402
S.D.	35.47	106.27	2,338.35	59.01	38.97	346.96	-	2,611.95	0.470

<sup>a</sup>Fossil fuel for farm machinery (production and utilization)

<sup>b</sup>Organic fertilizers (production and utilization)

<sup>c</sup>Chemical fertilizers (production and utilization)

<sup>d</sup>Energy for insecticide application (production and utilization) and insecticide production

<sup>e</sup>Energy for herbicide application (production and utilization) and herbicide production

<sup>f</sup>Energy for irrigation system; fossil fuel and electricity (production and utilization)

<sup>g</sup>Fossil fuel for transportation of product to central market (production and utilization)

### 3.4 Comparison between CF from organic and conventional farming

In conclusion, the CF of conventional farming was  $0.402 \pm 0.47$  kg CO<sub>2</sub>e/kg of Chinese kale (N=11), (Table 5) and the CF of organic farming was  $0.195 \pm 0.122$  kg CO<sub>2</sub>e/kg of Chinese kale (N=4), (Table 4). The difference in emissions related to farm management. The CF of conventional farming was about double that of organic farming. Because conventional farming was cultivated by applying a large amount of chemical fertilizer, fossil fuel for

farm operation and management, use of herbicide and insecticide to get more production and further product shipment to a central market (higher demand from consumer). In contrast, the organic farmers did not plant for sale to a central market, but for home consumption or for a nearby community market. The distances involved in the two systems differed, and so emission levels and CF were affected.

Conventional cultivation was found to be less environmentally friendly than organic cultivation when results are presented per unit of product

(Kaltasas et al., 2007; Florence et al., 2015; Sonia et al., 2017). Moreover, the researcher presented the results of energy analysis that indicate ways to decrease energy inputs without losses in production and profits. The choice of management style in organic olive groves can decrease energy inputs without losses in production, and different uses of fossil energy tend to result in lower CO<sub>2</sub> emissions (Kaltasas et al., 2007). Florence et al. (2015) studied organic and conventional wheat farming. Organic wheat is more environmentally friendly than conventional wheat in terms of global warming, photo-oxidant formation and energy demand. Sonia et al. (2017) compared the energy and environmental impacts of organic and conventional apples cultivated in northern Italy. The results showed that conventional apples could help to reduce environmental impacts, and detailed analysis of the farming step showed that a significant share of the overall energy and environmental impacts was from the use of fertilizers and pesticides, and the diesel consumption of agricultural machines. The CF and the key of CF hotspots of organic and conventional cultivation systems in Chinese kale in this study indicate that fossil fuel for transportation plays a very important role for organic cultivation, while chemical fertilizer utilization plays a very important role for conventional cultivation. There were similar results in a sugarcane plantation in Thailand, crop production in China, coffee in Costa Rica and spring wheat in Canada. These studies found the very large amount of conventional cultivation emissions come from chemical fertilizer use (Yuttitham et al., 2011; Kun et al., 2011; Martin et al., 2012; Yantai et al., 2012). In China, crop emissions analysis showed that the largest contribution (~60%) comes from fertilizers (Kun et al., 2011). The CF results in coffee comparing conventional and organic management revealed that 1 kg of fresh coffee cherries in conventional systems accounted for between 0.26 and 0.67 kg CO<sub>2</sub>e and organic systems accounted for between 0.12 and 0.52 kg CO<sub>2</sub>e. The main contributor to GHG emissions for all management systems were the inputs of organic and inorganic nitrogen (Martin et al., 2012).

Total GHG emissions and environmental impacts from organic cultivation were lower than that in conventional cultivation. These results are

similar to that of previous studies assessing organic versus conventional agriculture in many types of agricultural crops (Harpinder et al., 2010; Matthias et al., 2015; Spyros and Efthalia, 2016). One previous study of apple supply chains showed that 1 kg of apples had a GWP of 0.20 kg CO<sub>2</sub>e. The main contribution to the CF during cultivation was consumption of fuel for machinery, which changed significantly according to the distance from the farm center and the field size (Sessa et al., 2014). Some research output from the USA studying small organic vegetable farms found fuel use, organic fertilizer, soil emissions and irrigation as the major hotspots in CF in organic farming management (Adewale et al., 2016).

In this study, the CF of organic Chinese kale was 0.195±0.122 kg CO<sub>2</sub>e/kg of Chinese kale, as mentioned above. A review of other organic crops in Thailand found the CF of organic crop cultivation ranged from 0.0019 to 0.8780 kg CO<sub>2</sub>/kg of fresh product. This range includes the CF from acacia (0.0019 kg CO<sub>2</sub>/kg), hamate bean (0.0044 kg CO<sub>2</sub>/kg), garlic (0.0560 kg CO<sub>2</sub>/kg), string bean (0.0565 kg CO<sub>2</sub>/kg), guangdong (0.0739 kg CO<sub>2</sub>/kg), cabbage (0.1202 kg CO<sub>2</sub>/kg), Chinese cabbage (0.1621 kg CO<sub>2</sub>/kg), soybean (0.2496 kg CO<sub>2</sub>/kg) and asparagus (0.8780 kg CO<sub>2</sub>/kg) (Thailand Greenhouse Gas Management Organization, 2018). The CF of organic Chinese kale in this study has a relatively high footprint if compared with other crops in the Thailand database. The CF of conventional Chinese kale was 0.402±0.047 kg CO<sub>2</sub>e/kg of Chinese kale. When compared with other conventionally farmed products in the Thailand database, the CF sum ranged from 0.1223 to 2.5862 kg CO<sub>2</sub>/kg of fresh product. Table 6 shows the footprint from many types of crops (Thailand Greenhouse Gas Management Organization, 2018).

The CF from this study show relatively moderate values when compared with others. One CF from Chinese kale in the Thailand database showed a total CF of 0.159 kg CO<sub>2</sub>/kg of Chinese kale; this included emissions from cultivation (excluding emissions from transportation to the central market) (Thailand Greenhouse Gas Management Organization, 2018). The difference was mainly due to the inclusion of emissions from the use of materials in the cultivation process.

**Table 6.** The carbon footprint from conventional farming in Thailand database.

No.	Crop	Carbon footprint kg CO <sub>2</sub> /kg	No.	Crop	Carbon footprint kg CO <sub>2</sub> /kg
1	galangal	0.1074	16	sesame	0.3154
2	potato	0.1223	17	sweet corn	0.3262
3	guangdong	0.1338	18	tomato	0.3486
4	cauliflower	0.1457	19	paprika	0.3676
5	lemon grass	0.1494	20	black eyed peas	0.3684
6	carrot	0.1872	21	sweet pepper	0.3910
7	string bean	0.1897	22	garlic	0.4229
8	onion	0.2018	23	sweet basil	0.4447
9	lentils	0.2229	24	peanut	0.5528
10	kaffir lime fruit	0.2381	25	green beans	0.6999
11	cabbage	0.2555	26	lettuce	0.7771
12	shallots	0.2522	27	bamboo shoot	0.9272
13	maize	0.2670	28	pepper	1.1271
14	soybean	0.2898	29	kaffir lime leaves	2.5862
15	cucumber	0.3062			

#### 4. CONCLUSIONS

This study aimed to estimate the CF from organic and conventional farming of Chinese kale in Nakhon Pathom province, Thailand. In conventional farming, more than 50% of GHG emissions come from the use of chemical fertilizers. In organic farming, more than 80% of GHG emissions come from the use of fossil fuel transportation. The results are similar to those in previous studies. Chemical fertilizers accounted for the highest GHG emissions found in conventional farming. To reduce GHG emissions, therefore, farmers should reduce use of chemical fertilizers or be recommended to use the appropriate quantity of fertilizer. We already know that organic farming maintains land in good agricultural and environmental conditions and is beneficial to food safety, and animal health and welfare. The results of this study could be used to promote the planting of Chinese kale by organic farmers. More survey data are needed to study the sensitivity of the CF to such large variations in input data. Lack of specific data meant that stock changes in soil organic carbon and soil pollution were not accounted for in this study, and further research should consider these.

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