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Carbon Footprint of Mangosteen Farm Level Evaluation in Eastern Thailand

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Abstract

The study of the carbon footprint (CF) of agricultural crops provides important information that can help achieve low-carbon agriculture, but there are still very few studies on CF for farmed fruit. This research emphasized CF calculation for mangosteen crops at the farm level. The study was carried out on 55 mangosteen farms that belong to the Tambol Troknong Community Enterprise in the Khlung District of Chanthaburi Province, Thailand. The findings revealed that the product CF average was 1.71 ± 1.38 kg CO_2eq/kg, and the farm CF was 15,623.41 ± 16,981.27 kg CO_2eq/ha. The total CF was determined from six sources, including the application of substances such as fertilizers (organic and inorganic), pesticide and herbicide, as well as from the use of electricity and fuel. We found that most of the CF was direct emissions from electricity usage, which accounted for as much as 85.33% of the total CF. Thus, this research provides important information on the CF and level of production inputs. We developed guidelines for reducing greenhouse gas emissions from mangosteen production in the area.

Keywords: carbon footprint; life cycle assessment; greenhouse gas emission; GIS; spatial pattern
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1. Introduction

The issues of sustainable agriculture and climate change have become global concerns [1]. The concept of environmentally friendly farming has long been introduced, and it has been formulated as a policy to encourage farmers to save our Earth throughout the production chain by reducing the use of chemical fertilizers, pesticides, and herbicides. Such reduction is safer for consumers and can reduce production costs. It is well known that agriculture is one of the chief sources of greenhouse gas (GHG) [2], therefore, the great importance in sustainable agriculture is the investigation of the carbon footprint (CF) of plants [3]. CF in crop production is the amount of greenhouse gases released throughout the plant-production chain calculated in the form of carbon dioxide equivalent. Because it provides insights for farmers to more effectively view their crop-production practices, the study of CF is crucial. It helps farmers to be more aware of production factors related to farming and to plan to use them properly in the production system. Carbon labeling on the product can be a useful

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way to inform consumers of the amount of GHG expected to be released during the production process. Consumers can then choose to buy low-carbon products, which help promote low-GHG-emission agriculture, and reduces the impact on the environment [4, 5].

Life Cycle Assessment (LCA) principles are taken into account in CF calculations throughout the production process, e.g., production inputs, transport, distribution, and product-scraps disposal. CFs are used in agriculture, especially when growing crops such as beans and grains (rice, wheat, and corn) [6-10], potatoes and sugarcane [11], and organic vegetables [12, 13]. In previous studies, however, CF calculation was not applied to horticulture because of the long production time and harvest periods involved. It requires more time to record the data and the assessment is more difficult than for grain and field crops. Particularly in Thailand, there are only a few studies on the CF of horticulture. The Tambol Troknong Community Enterprise (TTCE) is located in Khlung District, Chanthaburi Province where it is one of high-quality mangosteen plants in Thailand. Previous studies investigated the CF of mangosteen production during the 2013 and 2016 production year and were focused on the calculation of CF for all member farms in TTCE [14, 15]. Therefore, in our study, we aimed to calculate the CF from mangosteen production by participating members of the Tambol Troknong Community Enterprise (TTCE) in the Khlung District, Chanthaburi Province. We focused on the 2019 production year. Using LCA cradle-to-gate principles, we covered the entire production process, obtaining relevant factors from production through harvest. Our research results provide insights into CF sources and level of emissions from mangosteen production at each farm. Also, the findings will be beneficial to farmers in governing factors involved in farming production, leading to effective reduction of costs and GHG emissions. Moreover, about 70% of TTCE's mangosteen production is exported to foreign countries. The major export markets are China, Korea and Japan. The trend of global trade has begun to focus on environmentally conscious and non-global warming goods or products. It is clear that our research can be seen as being part of a long-term plan for the benefit of exports to avoid problems with CF-related trade barriers that may occur in the future.

2. Materials and Methods

2.1 Study area

The study was carried out on 55 TTCE member farms in the Troknong subdistrict, Khlung District, Chanthaburi Province. The research project covered a total area of 4,361 ha (Figure 1). The Troknong subdistrict in Thailand is an area that has been chosen to be a green agricultural city. It is a good source of high-quality mangosteen plants and fruit. Most of the mangosteen products from this area are selected for export to foreign countries.

2.2 Boundaries of mangosteen farms

The process of delineating the boundaries of participating mangosteen farms initially included downloading satellite-image data for the Troknong subdistrict in 2019 from Google Earth and assigning a coordinate system for the image. Then the boundaries of the 55 mangosteen farms were digitized from the satellite imagery. Finally, all the farms' attribute data (farmers' names, addresses, areas, and other information) were created.

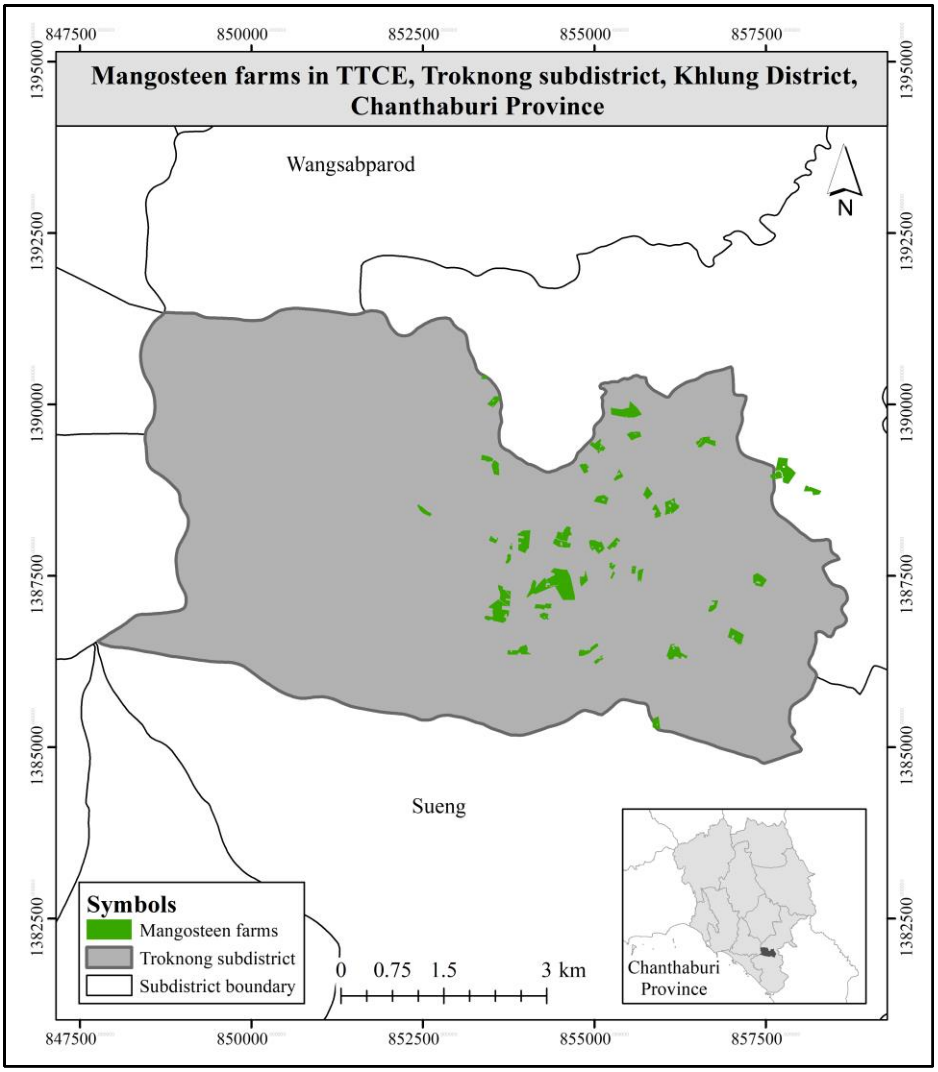

Figure 1. Study area: 55 mangosteen farms in Tambol Troknong Community Enterprise (TTCE), in Troknong subdistrict, Khlung District, Chanthaburi Province, Thailand

2.3 System boundary

This study aimed to investigate GHG emissions from mangosteen production at the farm level using LCA cradle-to-gate principles. We collected primary data on farm inputs, machinery (electric water pump and lawn mower), and transportation (inputs and yields) based on the actual records of the 2019 production year. The data included quantitative inputs (organic fertilizer, inorganic fertilizer, pesticide and herbicide, other substances, electricity, and fuel) [9, 16], outputs (products and wastes), and farm operation data that covered growth stages of mangosteens: shoot development (August-October 2018), inflorescence development (November-December 2018), flowering (January-February 2019), fruit development (March 2019), and fruit maturation (April-July 2019). The system boundary of CF calculation is illustrated in Figure 2.

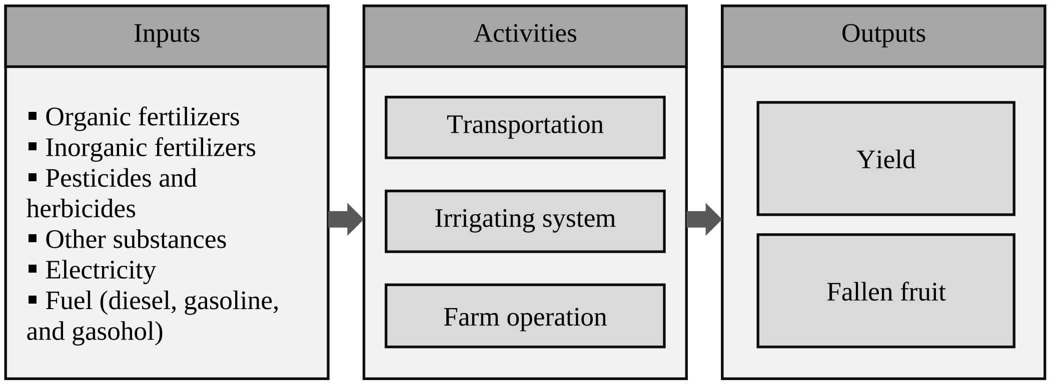

Figure 2. System boundary of the life-cycle CFs of mangosteens

In addition, on all 55 participating farms, it was specified that the trees must have fruits, and during the study period, farmers must not change land use (e.g., they were not permitted to cut down mangosteen trees and replace them with other crops). The CF was divided into two types: product carbon footprint (PCF) and farm carbon footprint (FCF). In this study, global warming potential (GWP) was assessed based on the direct and indirect emissions of carbon dioxide (CO_2) involved in mangosteen production activity for each farm [12].

2.4 Calculation of mangosteens' carbon footprint (CF)

CF calculations for mangosteen production were primarily based on the cradle-to-gate LCA concept, which covered the entire production cycle. This encompassed the entire production process in 2019 from the procedure to obtain the relevant factors related to fruit harvest. The data used in the CF calculation were obtained from in-depth interviews of the 55 farmers participating in the research project. The interview form was divided into six main groups of factors or usages affecting production: organic fertilizer, inorganic fertilizer, pesticide and herbicide, other substances, electricity, and fuel; the form was also designed to acquire other basic information such as number of mangosteen trees, production statistics, and the amount of wasted (fallen) fruit.

CF results are shown as carbon equivalent (kg CO_2eq) and are divided into two forms, product carbon footprint (PCF) and farm carbon footprint (FCF). PCF is defined as CF value per production unit (kg CO_2eq/kg) and FCF is CF value per unit area (kg CO_2eq/ha) [8, 16]:

$$\mathrm{PCF_n} = \sum \mathrm{I_i} \times \mathrm{EF_i} \tag{1}$$

$$\mathrm{FCF_n} = \mathrm{PCF} \times \mathrm{Y_n} \tag{2}$$

where I is the material or energy input (as kg/kg, l/kg, or kWh/kg), i is the kind of material or energy input, EF is GHG emission factor (kg CO_2eq/kg), Y is the yield per unit area of mangosteen production (kg/ha), and n is the number of farms.

Both PCF and FCF were calculated and shown on a base map using ArcGIS Desktop 10.0 software. Values for GHG emission factors from the Thailand Greenhouse Gas Management Organization in 2019 [17] were used in the CF calculations (Table 1).

Table 1. Greenhouse gas emission factors for calculating carbon footprint in mangosteen production

Material or energy usage	Emission factor	Material or energy usage	Emission factor
Chicken manure	0.32 kg CO_2eq/kg	Dolomite	0.03 kg CO_2eq/kg
Pig manure	0.26 kg CO_2eq/kg	Paraquat	3.23 kg CO_2eq/l
Cow manure	0.25 kg CO_2eq/kg	Glyphosate	16.00 kg CO_2eq/l
OF (pellet)	0.25 kg CO_2eq/kg	Abamectin	3.23 kg CO_2eq/l
OF (liquid)	0.18 kg CO_2eq/kg	Imidacloprid	3.23 kg CO_2eq/l
IF 15-15-15	1.50 kg CO_2eq/kg	Cypermethrin	3.23 kg CO_2eq/l
IF 8-24-24	1.14 kg CO_2eq/kg	Methomedfos	3.23 kg CO_2eq/l
IF 13-13-21	1.35 kg CO_2eq/kg	Chlorpyrifos	3.23 kg CO_2eq/l
IF 16-16-16	1.61 kg CO_2eq/kg	Surfactant	3.23 kg CO_2eq/l
IF 46-0-0	3.67 kg CO_2eq/kg	Flower-bud hormone	3.23 kg CO_2eq/l
IF 17-17-17	1.71 kg CO_2eq/kg	Zinc (liquid)	2.91 kg CO_2eq/l
IF 18-0-8	1.48 kg CO_2eq/kg	Mangosteen fermented water	0.89 kg CO_2eq/l
IF 20-15-15	1.91 kg CO_2eq/kg	Diesel fuel	2.74 kg CO_2eq/l
IF 18-4-5	1.53 kg CO_2eq/kg	Gasoline	2.24 kg CO_2eq/l
Sulfur powder	0.11 kg CO_2eq/kg	Gasohol fuel	2.24 kg CO_2eq/l
Hormone powder	0.25 kg CO_2eq/kg	Electricity	0.69 kg CO_2eq/kWh

Note: OF is organic fertilizer and IF is inorganic fertilizer.

3. Results and Discussion

3.1 Basic data

Mangosteen (*Garcinicmangostana* L.) is a large tropical evergreen tree with 6-25 m tall. The temperature range for growing and producing fruits is 25-35 °C, a relative humidity 75-85%, and soil with a pH of 5.5-6.5. Mangosteen trees may reach fruit – bearing in as little as 7 years. At age 30-45 years in full maturity, trees as old as 100 years still produce fruit [18].

According to a survey and data collection on all 55 mangosteen farms in 2019, a total combined area of 92.74 ha was planted with 11,023 mangosteen trees, which corresponds to an average planting density of 118.86 trees per hectare. The average age of the trees was 32 years. The youngest tree was 9 years (farm number 55) and the oldest tree was 71 years (farm number 4). Total useful yield was 855,067 kg; if fallen fruit (31,120 kg) was included, average yield was 9,555.85 kg/ha. Mangosteen cultivation averaged 76.79% in mixed orchards and 23.21% in single plantations. Five types of soil were found on the 55 mangosteen farms: sandy loam (64.29%), loam (21.43%), loamy clay (7.14%), sandy clay (5.36%), and clay (1.78%).

As for the production inputs used on the 55 mangosteen farms, we found that organic fertilizers and inorganic fertilizers totaled 165,047.45 kg and 29,379.25 kg, respectively; pesticides and herbicides totaled 681.65 l; and other substances amounted to 13,035 kg. As for energy consumed, electricity use was 1,576,882.02 kWh (for watering the mangosteen trees), and fuels (diesel, gasoline, and gasohol) totaled 1,296.71 l, which the farmers used the four-wheel trucks to transport inputs and yields (Table 2). Each farm transported inputs from store to farm and yields from farm to market. The average transport distance was 65.45 km; farm number 11 had the shortest distance of 36 km, and farm number 13 had the longest distance of 206 km. As this farm (number 13) had the most cultivated area of 7.36 ha, a large amount of production inputs was needed, and

Table 2. Inputs, output, and waste from mangosteen production in 2019

Item	Quantity	Unit
Input		
Organic fertilizers	165,047.45	kg
Inorganic fertilizers	29,379.25	kg
Pesticides and herbicides	681.65	l
Other substances	13,035.00	kg
Electricity	1,576,882.02	kWh
Fuels	1,296.71	l
Output		
Yield	855,067.00	kg
Waste		
Fallen fruit	31,120.00	kg

the yields were correspondingly large. Therefore, it had the greatest total distance of transport compared to other farms.

3.2 Product carbon footprints (PCFs) and farm CFs of mangosteen

From the PCF calculation for mangosteens, the mean and standard deviation were computed as 1.71 ± 1.3 kg CO_2eq/kg. There were 22 farms or 40% that were <0.89 kg CO_2eq/kg, which was the CF value for the standard 1-kg mangosteen [17]. When considering the PCF value for each farm, we found that farm number 16 had the lowest PCF, equivalent to 0.06 kg CO_2eq/kg. This farm has 35 mangosteen trees on 0.32 ha with a yield of 3,140 kg. The main reason why this farm had the lowest PCF was that it used very low amounts of inputs, especially energy usage in the form of electricity. Because it is near a waterfall (304 m), the farmers dug a channel to divert water from the waterfall into the mangosteen plantation without first having to pump water into a pond. This resulted in less electricity use and therefore very low PCF values compared to other farms of equal area (e.g., farm numbers 15 and 32 with PCFs of 1.72 and 2.63 kg CO_2eq/kg, respectively). Farm number 15 had very high electricity use, as it has 100 mangosteen trees (almost triple the number on farm number 16), so more water had to be pumped to irrigate the trees, whereas farm number 32 had very high organic fertilizer use (13.71 times more than farm number 16), despite the fact that there were only 50 mangosteen trees being grown on the farm. Farm number 50 had the highest PCF, equivalent to 4.72 kg CO_2eq/kg. It had 128 mangosteen trees on 1.28 ha with a yield of 5,564 kg, or 4,346.88 kg/ha (2.26 times less than farm number 16). Data for this farm (number 50) showed that the farm had higher production inputs but lower yields than did farm number 16. The main reason was that this farm was further from irrigation water (1,000 m), with other mangosteen farms separating it from the water source. Therefore, the farmers had to pump water into the pond on the farm before watering the mangosteen trees, resulting in higher electricity usage and PCFs than other farms. Farm number 13 was the largest farm with an area of 7.36 ha. It had the highest number of 800 trees with yield of 85,000 kg, equivalent to 11,548.91 kg/ha, which was 2.66 times more than farm number 50 because there was a good management system applied to farm number 13. It used less electricity than farm number 50 despite having more areas and trees. As a result, this farm (number 13) had a PCF value of only 0.32 kg CO_2eq/kg (Figure 3).

The mean and standard deviation for FCF for all 55 farms combined was 15,623.41 ± 16,981.27 kg CO_2eq/ha. With the lowest PCF and a yield equal to 9,812.50 kg/ha, farm number 16 also had the lowest FCF (636.48 kg CO_2eq/ha) of any of the farms. Farm number 26 had the highest FCF (79,354.76 kg CO_2eq/ha) and one of the highest PCFs (4.57 kg CO_2eq/kg), but its high yield (17,357 kg/ha) ranked it fourth among all 55 farms. Farm number 3 has the highest yield (19,062.50

kg/ha), but its FCF was low (11,818.80 kg CO_2eq/ha) because the PCF was only 0.62 kg CO_2eq/kg. Farm number 55 has the lowest yield (1,444.71 kg/ha), but its FCF was 28,797.90 kg CO_2eq/ha, while its PCF was almost the highest of all (4.60 kg CO_2eq/kg). The main reason was the use of electricity to pump large quantities of water to the mangosteen trees. However, it had much lower yield than other farms, resulting in a very high CF of 1 kg of mangosteen (Figure 3).

Figure 3 presents the relationship between the PCF and the FCF in the same direction, when the PCF was high, the FCF was high as well. However, when considering the top five PCF values, it was found that there were three farms that did not correlate in the same direction: farm number 50 (PCF = 4.72 kg CO_2eq/kg, FCF = 20,517.20 kg CO_2eq/ha), farm number 23 (PCF = 4.42 kg CO_2eq/kg, FCF = 11,301.10 kg CO_2eq/ha), and farm number 55 (PCF = 4.60 kg CO_2eq/kg, FCF = 28,797.90 kg CO_2eq/ha), since all three farms had very low yields with 2,556.82, 4,346.88, and 1,444.71 kg/ha, respectively. In particular, farm number 55 had the lowest yield compared to other farms. This shows that these farms used large quantities of inputs, but produced low yields and also high CFs. Therefore, these farms may need to be improved and planned for the use of inputs properly such as timing and volumes for watering the mangosteen trees, soil examination for fertilizers that is consistent with soil properties.

In the 2019 production year, TTCE had a total CF of 1.40×10^6 kg CO_2eq/yr. The total mangosteen production was 886,187 kg, which was equal to 0.25% of the total mangosteen production in Thailand, which was 351,760,000 kg [19]. We roughly estimated the CF of the remaining 99.75% of the country's mangosteen production in 2019 to have been 5.55×10^8 kg CO_2eq/yr.

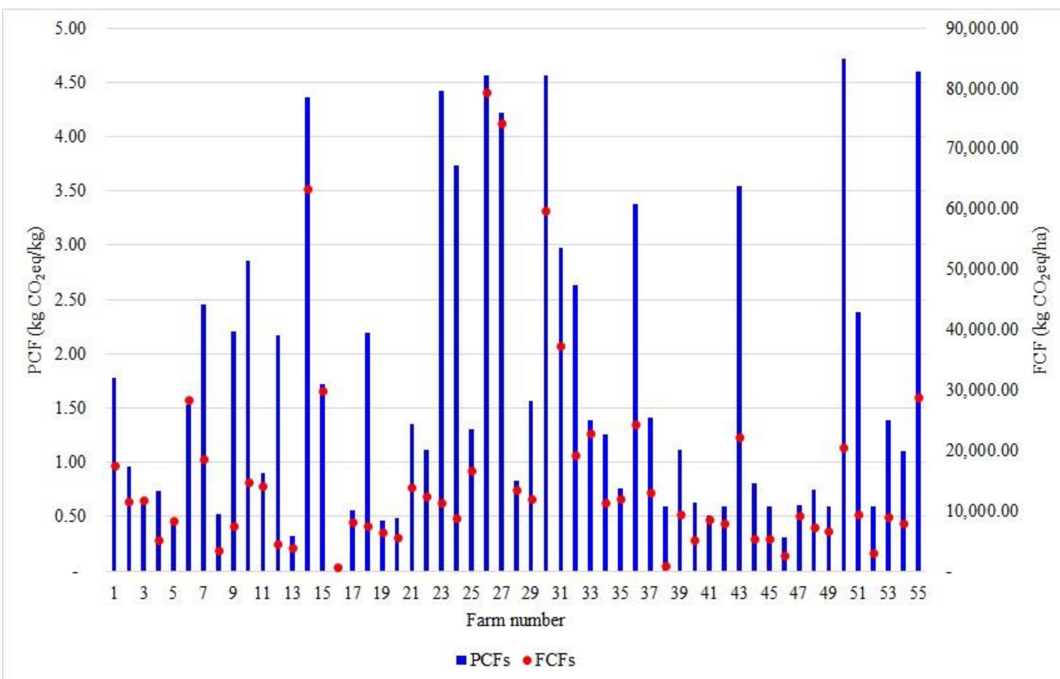

Figure 3. Product and farm carbon footprints of mangosteens in the production year 2019

The inputs used in mangosteen production were organic fertilizer, inorganic fertilizer, pesticide and herbicide, other substances, electricity, and fuel. When calculating the proportion of inputs that contributed towards CF from the production of 1 kg of mangosteen, we found that electricity was highest (85.33%); it was used mainly for pumping water to the mangosteen trees. During the dry season (November-February), no rain fell in the area, but the mangosteen trees still needed water, especially during February continuing into March, when the trees needed water to nourish the young fruit and support their growth. The farmers had to meet this demand by pumping water from wells or irrigation canals using electricity. As a result, a large amount of electricity was used, and that had an impact on CF. The inputs with the next-highest impacts were organic fertilizer and inorganic fertilizer, accounting for 8.92% and 4.67%, respectively. Even if the inorganic fertilizer had a higher emission factor than organic fertilizer, the amount of organic fertilizer used (165,047.45 kg) was 5.62 times higher than that of inorganic fertilizer (29,379.25 kg), thereby making the proportion of organic fertilizer greater than inorganic fertilizer which was an advantage that farmers in TTCE used organic fertilizers rather than inorganic fertilizers. This is because organic fertilizer has a much lower emission factor than inorganic fertilizer. Most importantly, organic fertilizer leaves no residue and can affect the health of consumers (Figure 4).

Regarding other input amounts, we found that the farmers used only small amounts, each <1%, and thus had little impact on CFs. Pesticide and herbicide used were 0.53% and other substances used (such as flower-bud hormone and zinc) were only 0.21%. Fuel including diesel, gasoline, and gasohol, which were mostly used in trucks to transport mangosteens and inputs, amounted to 0.34%. It can be seen that farmers used fuel only for transportation, as fuel is expensive. When they wanted to pump water to the mangosteen trees, they chose to use an electric water pump, which was cost-effective rather than using fuel (Figure 4).

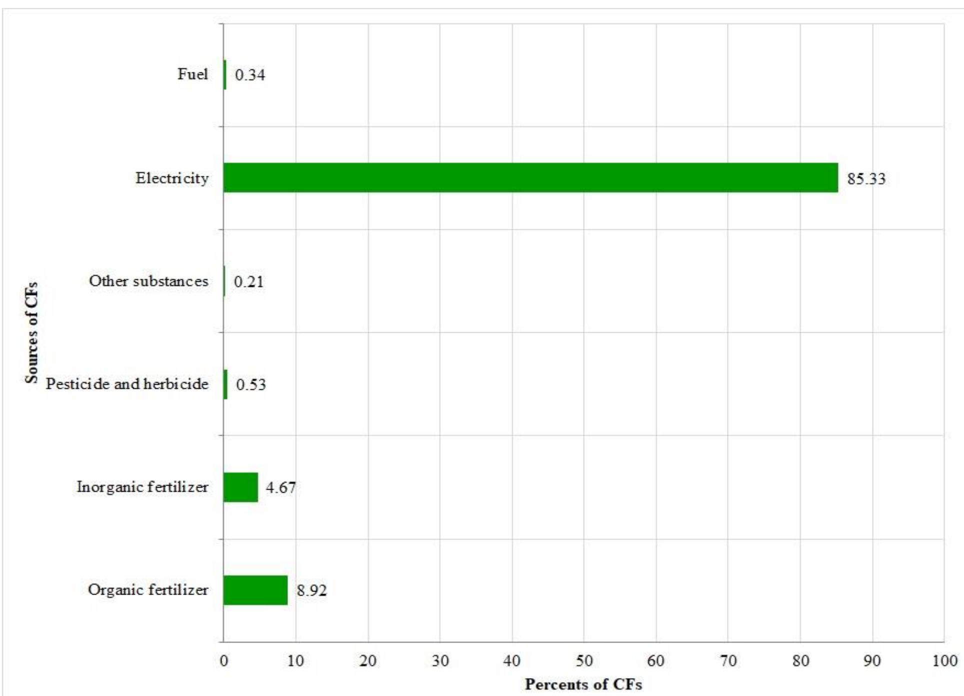

Figure 4. Proportions of carbon footprint sources per kilogram of mangosteen production by TTCE (55 participating farms) in the production year 2019

3.3 Spatial pattern of PCFs

The spatial distribution of PCFs for the mangosteen farms was unpredictable, meaning that those with low or high PCFs were scattered throughout the subdistrict (Figure 5). At the north end of the subdistrict and near the waterfall (304 m) that it used, farm number 16 had the lowest PCF (0.06 kg CO_2eq/kg). Farm number 46, in the middle of the subdistrict and also close to water sources (50 m), had a higher PCF (0.31 kg CO_2eq/kg), similar to that of farm number 32 (0.32 kg CO_2eq/kg), which was also central in the subdistrict and close to water sources (65 m). Farm number 50, in the southwestern part of the subdistrict and away from water sources (1,000 m), had the highest PCF (4.72 kg CO_2eq/kg). We, therefore, concluded that farms with low or high PCF were not related to the location or to the distance from the water source, although the distance from the water source did affect electricity usage when pumping water to the mangosteen trees. For farms near water sources or irrigation canals, the farmers could divert or pump water directly, but for those far from water sources, they first had to pump water into holding ponds. Accordingly, farms that were far from water sources likely used more electricity than those near water sources, thereby affecting the CF.

The distribution of low to high PCFs calculated from the production of 1 kg of mangosteen (kg CO_2eq/kg) (Figure 5) shows that they were dispersed across the area with unpredictable patterns. Most TTCE farmers watered their mangosteen trees in accordance with patterns that were previously practiced, on a definite schedule and with a set amount of irrigation, regardless of weather conditions. They did not use rain-forecast data to plan watering their crops. Occasionally it rained when they were watering the mangosteen trees, thereby causing the trees to receive higher amounts of water than necessary. Watering the trees required electricity use, which directly impacted CF. Another important factor affecting the distribution pattern of PCF is soil type. Based on a survey of the TTCE mangosteen farms, most of the soils on the farms were sandy loam; four other types were loam, loamy clay, sandy clay, and clay. The different soil types would also have affected water consumption on mangosteen farms.

We compared PCFs for the 55 different farms with those of the standard PCF (0.89 kg CO_2eq/kg) set by the Thailand Greenhouse Gas Management Organization [17]. We classified the 55 farms as follows: Of the 28 mangosteen farms that were close to water sources or irrigation canals, 11 farms had PCFs lower than those standard values, and the other 17 exceeded the standard values. Of the 27 mangosteen farms that were far from water sources or irrigation canals, 10 farms had PCFs lower than the standard PCFs, and the other 17 exceeded the standard values (Figure 5). Thus, whether the farms were near or far from water sources apparently had little or no effect on the PCF for each farm. PCF mainly depended on the watering pattern, soil types, and number of mangosteen trees planted on each farm.

4. Conclusions

Agriculture is one of the causes of the CF. When investigating the origin and quantity of CF for mangosteen production on a farm basis, the results of this study can be used to determine ways to more usefully reduce CF in the production process. According to data for the 55 TTCE mangosteen farms, the average PCF (1.55 kg CO_2eq/kg) was higher than the standard PCF set in 2016. The main cause of the higher CFs was electricity use to pump water to the mangosteen trees. Therefore, one way to reduce CF is to reduce water use, but watering must be in line with the needs of the mangosteen trees by introducing the farmers to proper knowledge and technology so that they can improve the crop-watering pattern or schedule. For instance, they can use the Meteorological

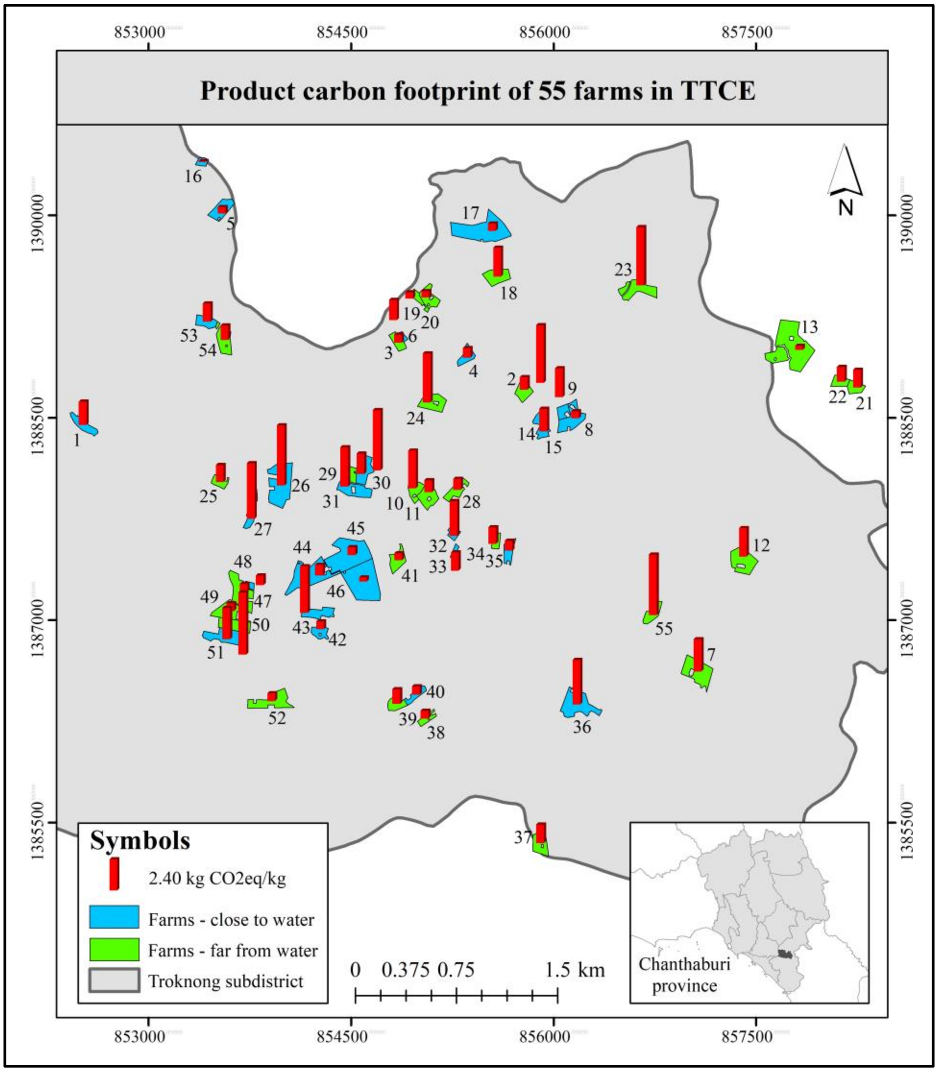

Figure 5. Product carbon footprints (PCFs) of 55 farms in TTCE in the production year 2019

Forecast Rainfall Application to help them plan the water supply for the mangosteen trees. This would help them provide amounts and timing of water application that are consistent with the weather and that do not exceed the water needs of the mangosteen trees. This can also result in saving electricity, time, labor, and costs, thereby ultimately reducing CF.

Because the production period is longer than that of crops such as rice and other cereal grains, and it takes a long time to collect the data, and there are very few studies on the CF from horticulture. In particular, the study of the mangosteen CF is new, and the only prior studies in Thailand were done on TTCE plantations and were the first CF studies in the production years 2013 and 2016 done by the Regional Office of Agricultural Economics 6. This ongoing research collected data on the mangosteen farms in the 2019 production year. It provides important information forecasting the trend of CF change in each production year and helps in determining ways to sustainably reduce CF. It also raises farmers' awareness of using the right amounts of inputs and having the least environmental impact. Another potential benefit is that it will help prevent future trade barriers from countries around the world. We, therefore, consider the CF study of TTCE mangosteen production to be a long-term effort that is in line with the changing system of global trade, which is becoming more environmentally conscious of the global-warming issue.

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