Carbon footprint analysis of the cultivated banana cultivation in Prachinburi Province, Thailand

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Abstract. This study aimed to estimate the carbon footprint and analyze the environmental hotspots of the cultivated banana cultivation in a case study of Prachinburi Province in Thailand. In addition, the study proposed the mitigation of the carbon footprint. Primary data were obtained from eleven Prachinburi banana farmers. The banana farmers were interviewed using a questionnaire. Planting area, plant spacing, yield, land preparation, planting, fertilization, irrigation, and harvesting were among the data collected. The results revealed that the carbon footprint of cultivated banana cultivation was 117 g CO_2e/kg of fresh cultivated banana, with fertilization accounting for 83 percent of the total. To predominantly reduce greenhouse gas emissions, the usage of fertilizer should be reduced. Different parts of the plants, such as trimmed leaves, de-suckered shoots, and stems should be chopped into small pieces and spread over the soil where the bananas are planted to nourish the plants without supplemental fertilizer. However, the reduced usage of fertilizer for banana cultivation should be studied along with the productivity of the crop.

Keyword. Carbon footprint, Cultivated banana, Cultivation

1 Introduction

One of the most important challenges of our day is global warming. Excessive greenhouse gas emissions caused by human activities have resulted in many changes including shifting global weather patterns, causing a disturbance in nature's normal balance. Current and future emission rates will likely cause additional global warming, further instigating such changes with irreversible impacts [1].

Effective mitigation of greenhouse gas emissions has been encouraged and practiced globally as a drastic consequence of global warming. The attempts include the reduction of emissions along the product or service supply chain, which are the producers in the manufacturing and agricultural sectors, the providers in the service sector, and the consumers. It is necessary to provide relevant information about the product or service, such as its carbon footprint [2], to assist customers in making ecologically friendly decisions.

Thailand is known as an agricultural country. It has tropical weather because of its proximity to the equator. This weather, which is warm and humid, allows the cultivated banana, or *kluai nam wa*, as it is known in Thai, to be grown everywhere all year round. Therefore, the cultivated banana should be marketed as another potential economic crop supplied in the local marketplace and the export marketplace as either fresh fruit or processed products [3].

The cultivated banana is a cross between two species of wild bananas - *Musa acuminata* and *Musa balbisaina* and belongs to the ABB genome group [4]. The scientific name of the cultivated banana is *Musa ABB* cv. *Kluai 'Namwa'* or *Musa sapientum* Linn. (family Musaceae) [5].

The cultivated banana is a 3–4 meters tall herbaceous perennial that is big, leafy, monocotyledonous, and clump-forming. Underground rhizomes produce leafy shoots. What looks to be a trunk is actually a pseudostem made up of tubular sheaths that are closely furled. Leaf-blades are up to one meter long, oblong, green, waxy, and smooth. The inflorescence develops from the top of the pseudostem once the plant has reached maturity and consists of numerous bracts covering rows of flowers. Fruits grow from female flowers in a large hanging bed cluster known as a bunch. [6]. Banana trees have a lifespan of approximately six years. Every year, each stem produces only one crop of bananas. The pseudostem dies after fruiting. Suckers (ratoons or followers), which are small plants that sprout from the rhizome at the base of the parent plant, are how bananas reproduce and furnish the next crop. [7].

It has been reported that 100 grams of edible ripe cultivated banana have 143 kilocalories, 1.1 grams of protein, 0.2 grams of fat, 33.1 grams of carbohydrate, 2.3 grams of dietary fiber, 7 milligrams of calcium, 43 milligrams of phosphorus, 0.8 milligrams of iron, 5

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micrograms of vitamin A, and 11 milligrams of vitamin C [8]. Cultivated bananas can be used for a wide range of dietary uses due to their high nutritional value. The fruits can be eaten raw or cooked when they are ripe. They can be mashed and used as baby food or dried and turned into snacks, such as banana chips [6]. Unripe green fruit contains a significant amount of starch, making it a rich source of resistant starch [9]. Banana flowers are consumed as a vegetable. Furthermore, after the fruits have been eaten, the banana peels can be extracted to yield prebiotics that can be used in a variety of foods [10, 11].

For other purposes, especially in Thailand, banana leaves are used for food or dessert wrapping. Parts of the banana trunk are used for decoration in traditional or religious activities [12]. The residual parts of the banana can be used for feedstock or soil improvement.

As a research project under a research program entitled "Raising local plants through research and innovation to a new economic crop", it is necessary to add value to fresh fruit and processed products for the cultivated banana by being conscious of environmentally friendly production to maintain its competitiveness and to lead a low-carbon and environmentally friendly economy [3]. However, it does not appear that a study on the environmental impact of cultivated banana cultivation has been conducted in Thailand or possibly elsewhere. Therefore, this study aimed to analyze the carbon footprint of cultivated banana cultivation in a case study of Prachinburi Province in Thailand. The study also identified the possible hotspots and proposed the mitigation of greenhouse gas emissions.

2 Methodology

2.1 Life cycle assessment and carbon footprint

In this study, a life cycle assessment (LCA) was obtained as an evaluation tool. LCA compiles inputs and outputs and evaluates the potential environmental impacts of products or services throughout their life cycle from raw material extraction through manufacturing, transportation, usage, and disposal [13]. Therefore, LCA is a holistic assessment approach for products or services and has been proved to be a valuable tool for documenting the environmental considerations that need to be part of decision-making in order to achieve environmental sustainability [14].

Carbon footprint is the method to evaluate the potential global warming based on the LCA principle. It is expressed in terms of the amount of carbon dioxide (CO_2), with the addition of its equivalent (CO_2e) in other greenhouse gas emissions specified by the Kyoto Protocol including methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Carbon footprint evaluations provide valuable background information for strategic and operational planning to promote greenhouse gas emission reductions.

2.2 Study scope and system boundary

This study focused on the cultivation of the cultivated banana in Prachinburi, Thailand. The purpose of the study was to analyze the carbon footprint of cultivated banana cultivation, in a case study of Prachinburi Province, to identify possible hotspots and propose the mitigation of greenhouse gas emissions. The functional unit providing a reference to which the inputs and outputs are related was defined as "1 kg of the cultivated banana in a whole bunch form".

The system boundaries of this study are illustrated in Fig. 1. The system boundaries follow a cradle-to-gate approach including land preparation, planting, fertilization, irrigation, harvesting, as well as the production of resources and energy utilized during cultivation. Transportation was excluded from the system boundaries.

2.3 Calculation of cultivated banana cultivation carbon footprint

In this study, primary data were obtained from eleven Prachinburi banana farmers. A questionnaire was prepared and the banana farmers were interviewed. Information collected included: planting area, plant spacing, yield, land preparation, planting, fertilization, irrigation, and harvesting. Practices vary among farmers. Amounts of resource and energy consumption related to the system boundaries were directly collected from the farmers interviewed in Prachinburi Province, Thailand. Greenhouse gas emissions from all cultivation activities were calculated using the multiplication amount of resources, or energy and emission factors obtained from the national database and other literature (Table 1) as shown in Eq. 1 and expressed as the amount of the carbon dioxide equivalent (CO_2e).

$$CO_2e = activity\ data\ x\ emission\ factor \tag{1}$$

Table 1. Greenhouse gas emission factors.

Activity	Unit	Emission factor (kg CO_2e/unit)	Sources
Resource and energy production			
- Diesel	kg	0.3522	[15]
- Lime	kg	1.0676	
- Chicken manure	kg	0.1097	
- Electricity	kWh	0.5986	
Cultivation			
- Combustion of diesel for land preparation	L	2.745	[16]
- Chicken manure application	kg	0.3157	

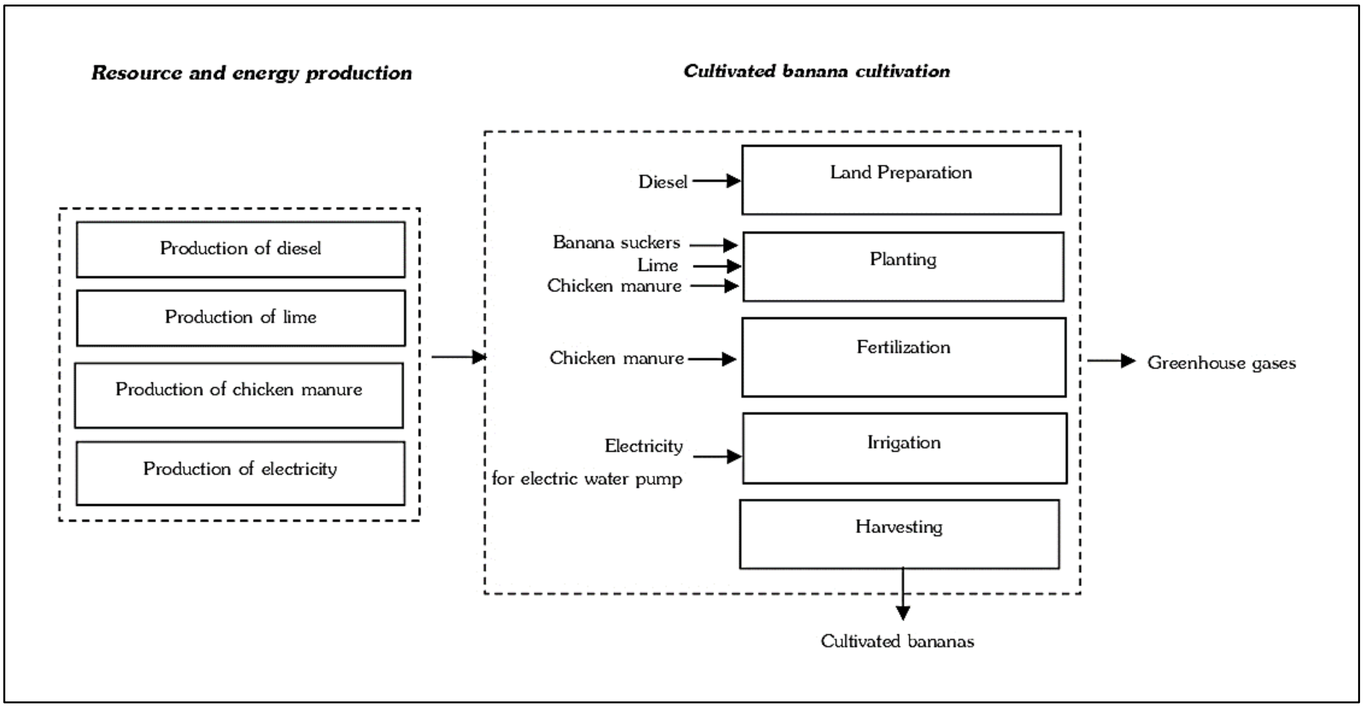

Figure 1. The system boundaries of the study.

3 Results and discussion

3.1 Cultivated banana cultivation in Prachinburi

The following is information on cultivated banana cultivation in Prachinburi.

3.1.1 Land preparation

For the preparation of the land, tractors were employed for tillage. From the information obtained from the field test in Prachinburi, the amounts of diesel consumed for primary tillage and secondary tillage were 5.5 L and 4.5 L per rai (1 rai = 0.16 ha), respectively [17].

3.1.2 Planting

Bananas are perennials that generate succeeding generations of crops. The first cycle after planting is called the plant crop. The ratoon is the sucker (also called the follower) succeeding the harvested plant.

Prachinburi farmers used banana suckers obtained from their orchards or from their neighbors to establish new banana orchards.

According to the recommendation, the planting pit should be around 50 cm × 50 cm × 50 cm with 4 m × 4 m spacing (100 plants per rai). As in the backyard garden and conventional practice, the cultivated bananas in Prachinburi averaged 50 parent plants per rai. For this activity, 3 kg of chicken manure and 2 kg of lime (to reduce soil acidity) were applied per planting pit. Human labor was used in every step of the planting process.

3.1.3 Fertilization

According to the interviews, no farmers in Prachinburi used chemical fertilizers, pesticides, or herbicides on their banana orchards. Farmers applied an average of 7.50 kg of chicken or cow manure per 1 pit every year to nourish their plants. The manure was applied during the vegetative stage and before the flowering stage. The inventory was analyzed based on the preference for chicken manure.

3.1.4 Irrigation

Supplemental irrigation has been necessary for the dry season. In general, an electric pump is used to pump water from a river, pond, or other water sources for banana irrigation. According to the questionnaire, the size of the electric pump, frequency, and interval of irrigation varied among the farmers. From background calculations, the average electricity supplied for the electric water pump was 0.0041 kWh/week for 1 planting pit of cultivated banana. Meteorological data showed the amount of precipitation, which can determine the dry period (precipitation less than 60 mm) of Prachinburi, which lasted for five months, from November to March [18]. For the inventory analysis of the study, it was determined that 22 weeks/year of supplemental irrigation was required.

3.1.5 Harvesting

Around 12 months after planting, bananas are ready to harvest. For this study, it was assumed that in one planting period, bananas can be harvested from the plant crops (the parent plant) and their ratoons for 4 years. Within 4 years, one plant crop produced 11 ratoons. With the average of 50 parent plants/rai in Prachinburi, there were 600 plants per rai including the parent plants and their ratoons.

A single crop is produced by each banana stem. As a result, 600 banana plants yielded 600 banana bunches within one planting period. In Prachinburi, the average yield was 12 kg per bunch, 8 hands per bunch, and 15 bananas each hand. The bananas were harvested by hand and carried to local markets.

3.2 Life cycle inventory of the cultivated banana cultivation in Prachinburi

Information on the cultivation practices obtained from Prachinburi farmers was analyzed. Table 2 presents the inventory data from the cultivated banana cultivation in Prachinburi based on 1 rai of the banana orchard in one planting period (4 years). Suckers, diesel, lime, chicken manure, electricity, and banana yield were among the items in the inventory of banana cultivation.

Table 2. Life cycle inventory analysis of banana cultivation.

Inventory	Unit	Quantity (per rai)
Input		
Suckers	Plants	50
Diesel	L	10
Lime	kg	100
Chicken manure	kg	1,650
Electricity	kWh	18.04
Output		
Banana yield (a whole bunch)	kg	7,200

3.3 Carbon footprint analysis of the cultivated banana cultivation in Prachinburi

Greenhouse gas emissions from cultivated banana cultivation were calculated and illustrated in Table 3. The cradle-to-gate carbon footprint of the cultivated banana cultivation was 117 g CO_2e per 1 kg of the whole bunch of the cultivated bananas. Fig. 2 provides a relative breakdown of the carbon footprint by source. Fertilization either in terms of fertilizer production or N_2O emissions, along with fertilizer application, contributed significantly to greenhouse gas emissions. Fertilization was responsible for 83% of greenhouse gas emissions.

Table 3. Greenhouse gas emissions from cultivated banana cultivation in Prachinburi Province.

Activity	Greenhouse gas emissions	
	(g CO_2e/kg banana)	Percent
Resource and energy production		
- Diesel	0.416	0.35
- Lime	14.828	12.62
- Chicken manure	25.140	21.40
- Electricity	1.500	1.28
Banana cultivation		
- Combustion of diesel during land preparation	3.241	2.76
- Chicken manure application for plant nourishment	73.248	61.59
Total	117.472	100

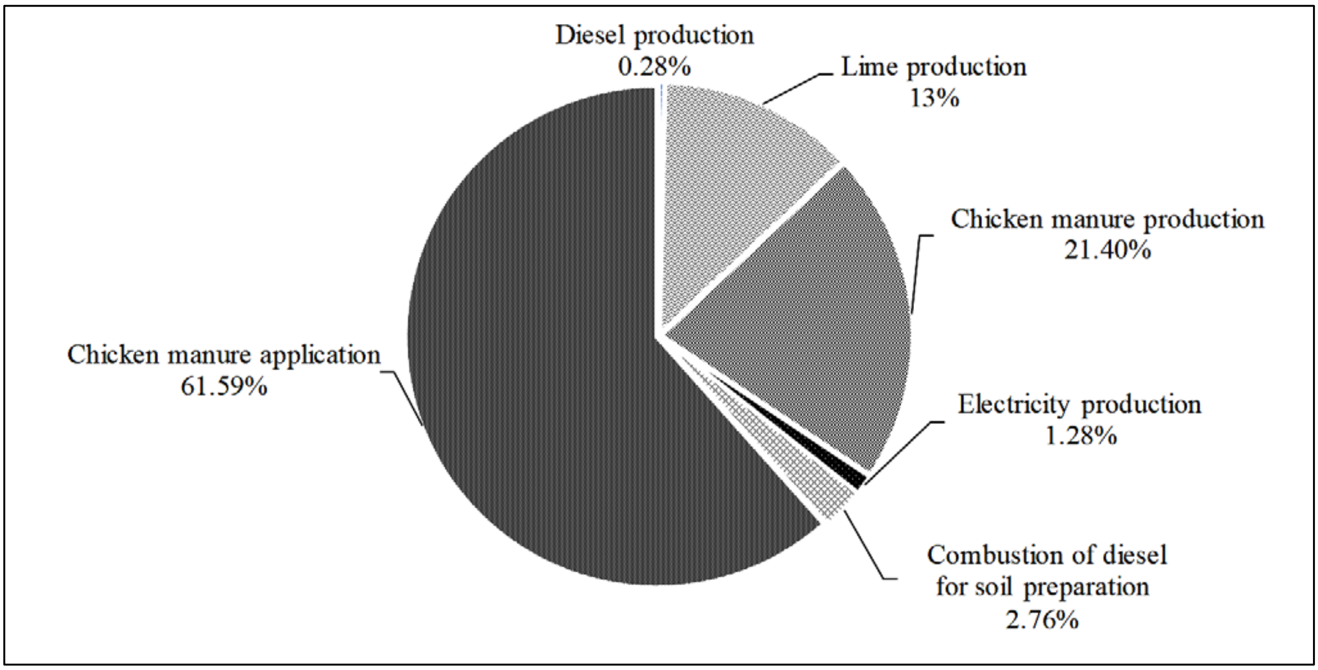

Figure 2. Carbon footprint breakdown of cultivated banana cultivation in Prachinburi Province.

As fertilization was dominant in contributing to greenhouse gases despite organic fertilizer usage, the mitigation of the carbon footprint should be achieved by reducing the use of fertilizer. One article [19] suggested that different parts of bananas, such as trimmed leaves, de-suckered shoots, and stems cut after harvesting, should be chopped into small pieces and spread over the soil where bananas are planted to increase soil nourishment without any supplemental fertilizer. The best way to replenish the nutrients that plants require is to bring pieces of the same plant to nourish it. However, the reduced use of fertilizer in banana cultivation should be investigated alongside the crop's productivity.

3.4 Discussion

3.4.1 Carbon footprint uncertainty

Several factors may cause the uncertainty of the carbon footprint analysis. Gathering all the essential data proved difficult, due to the variety of cultivation practices. The planting technique, the fertilization application, the irrigation, and other factors varied among farmers.

This study also used the lower end and the upper end of the inventory data to provide a minimum value and a maximum value of the possible carbon footprint for this case study. The carbon footprint varied from 28 to 246 g CO_2e/kg of banana. The findings were in line with the prior assessment that fertilizer was responsible for the majority of greenhouse gas emissions from banana production.

3.4.2 Carbon footprint comparison of the cultivated banana with other banana cultivars

It does not appear that there has been a study on the environmental impact of cultivated banana cultivation in Thailand or perhaps in other countries. For Cavendish bananas, only a few carbon footprint analyses have been published, and the results have varied depending on data and the methodology, such as defined system boundaries. Carbon footprints of a Cavendish banana supply chain ranged from 324 to 1,124 g CO_2e/kg of banana. Focusing on the primary stage, the greenhouse gases generated on farms, cradle to retail, were between 16% to 20% [20]. Therefore, the amount of carbon footprint from the cultivation was 52 to 225 g CO_2e/kg of banana. Another study analyzed the carbon footprint of Cavendish banana cultivation in Costa Rica. The result revealed a carbon footprint of 220 g CO_2e/kg of banana [21]. The carbon footprints of Ecuadorian bananas grown on conventional farms and organic farms were 302 g and 249 g CO_2e/kg of banana, respectively [22].

These amounts of carbon footprint were compared to the 117 g CO_2e/kg banana obtained from our study. Our outcome was lower because of the use of manure instead of chemical fertilizer, no energy-intensive activity for land preparation and planting, as well as no use of any pesticide or herbicide. Furthermore, the system boundaries of our study followed a cradle-to-gate approach, excluding packing bananas in carton boxes. The carton boxes are the most important factor that produces a high carbon footprint [20]. However, fertilization played a significant contribution to greenhouse gas emissions for banana cultivation in all studies.

3.4.3 Carbon footprint comparison of the cultivated banana with the other crops in Prachinburi Province

There were studies of carbon footprint analysis of crops in Prachinburi, which covered sugarcane [23], cassava [24], and Napier Pakchong 1 grass [17]. The carbon footprints of these crops as well as the cultivated banana were calculated per 1 hectare (ha), and were 3,463, 1,537, 1,727 and 1,320 kg CO_2e/ha, respectively. Sugarcane contributed the highest carbon footprint as compared to other crops. The majority of the carbon footprint of sugarcane was from greenhouse gas emitted from pre-harvest biomass burning. For other crops, the carbon footprint was affected by fertilizer application in terms of type and quantity.

4 Conclusion

This study aimed to estimate the carbon footprint and to analyze the environmental hotspots of the cultivated banana cultivation in a case study of Prachinburi Province in Thailand. In addition, the study proposed the mitigation of the carbon footprint. Primary data were obtained from eleven Prachinburi banana farmers. The banana farmers were interviewed using a questionnaire. Planting area, plant spacing, yield, land preparation, planting, fertilization, irrigation, and harvesting were among the data collected.

According to the results, the carbon footprint of cultivated banana cultivation was 117 g CO_2e/kg of fresh cultivated banana, with fertilization accounting for 83 percent of the total. To predominantly reduce greenhouse gas emissions, the consumption of fertilizer should be reduced. However, the reduced usage of fertilization for banana cultivation should be further studied along with the productivity of the crop.

Due to the variety of cultivation practices that cause the uncertainty of the carbon footprint analysis, more banana orchard samples should be considered. In addition, the orchards should be classified by size to make the analysis and the conclusion comprehensible.

Carbon footprint assessment of plant-based products is often a part of efforts to shift to more sustainable practices, both at the farm or cultivation stage and throughout the supply chain [25]. Further research along the supply chain is highly recommended for the cultivated banana in Thailand as fresh fruit or processed products, in order to raise local plants as a new economic crop.

Acknowledgments

This work was supported by (I) King Mongkut's University of Technology North Bangkok (KMUTNB), and (II) the National Science, Research and Innovation Fund (NSRF), Contract Number: KMUTNB-BasicR-64-38-3.

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