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Carbon footprint assessment of producing the bamboo shoots for commercial purposes

Tokhun, N.[1*], Somparn, A.[2], Iwai, C. B.[3] and Nuiplot, N.[4]

[1]Faculty of Science and Technology, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani Province, Thailand; [2]Office of General Education, Udon Thani Rajabhat University, Udon Thani, Thailand; [3]Integrated Land and Water Resoures Management Research and Development Center in Northeast Thailand, and Faculty of Agriculture, Khon Kaen University, Thailand; [4]Office of General Education, Valaya Alongkorn Rajabhat University under the Royal Patronage, Pathum Thani Province, Thailand.

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Abstract The assessment showed that the total carbon footprint of all activities was 227.7154 kgCO_2e/ton. Among them, the transportation sector which marked to deliver the product from the production sites in Prachinburi province to the central market in Nakhon Pathom province contributed to the highest carbon footprint of 113.550 kgCO_2e/ton, followed by the material acquisition sector (soil preparation and cultivation) and the production sector (trimming and cleaning yields) which contributed to the carbon footprint values of 99.842 and 14.324 kgCO_2e/ton, respectively. The results showed that the use of fertilizer in the material acquisition and transportation sectors should be considered for reducing energy consumption or making the most efficient use of resources, which reduced greenhouse gas emissions and also saved the production costs.

Keywords: Greenhouse gas, Carbon footprint, Emission factor, CO_2 emission, Bamboo cultivation

Introduction

Bamboo is known as a multi-purpose plant that grows so quickly that can replace the cut ones in a very short period of time, making it a resource with high and sustainable replacement potential. Thailand has appropriate factors for the distribution and growth of various types of bamboo throughout the regions, especially in mixed deciduous and deciduous dipterocarp forests. According to the survey, out of the 1,225 – 1,500 bamboo species in 75 – 105 genera recorded globally, 72 bamboo species in 17 genera were found throughout Thailand (Royal Forest Department, 2019; Boonsermsuk *et al.*, 2010). Though most of the

* **Corresponding Author:** Tokhun, N.; **Email:** natsima@vru.ac.th

bamboo utilized were from natural forests, the demand of bamboo farming is growing nowadays as bamboo is used as a raw material at the household to large industry levels. It was found that the value of processed bamboo product exports from 2015 to 2019 tended to increase, with the total export valued 587.16 million Baht (THB) in 2019, mainly from food products. At the same time, there were also bamboo products imported at a total value of 238.07 million Baht. However, when comparing the value of exports and imports of bamboo products, it was found that the value of exports was 2.47 times greater than the value of imports (Thai Customs, 2020). In addition, some countries such as China, Japan, Vietnam, Myanmar and Indonesia also take part in exporting bamboo products, revealing that they are among high-potential countries in terms of bamboo production. This emphasizes that Thailand still has a need for technological development in order to make products of comparable quality with foreign countries, especially in Prachinburi Province where bamboo is cultivated for commercial purposes. In 2023, the original bamboo planting area in Prachinburi was 30,291 rai, representing 38% of the country's total bamboo planting area of 95,935 rai. Among these, 6,859 rai of the field was ready for being harvested, yielding the bamboo product of up to 3,414,578 tons (Department of Agricultural Extension, 2021). The varieties of bamboos that farmers prefer to cultivate are Sri-Prachin bamboo—a kind of Phai Tong, Sang Mon bamboo, and Hedge bamboo (INBAR, 2021). Especially, the "Sri-Prachin" species which was originally developed at the garden of Mrs. Sa-ard Jaichueam in Prachinburi Province is the economic plant of the province and is characterized by its rapid maturation, good shoot development and the ability for the shoot to be harvested after only 1-2 years of cultivation (Laoprasert, 2019). Sri-Prachin bamboo can generate a net profit for farmers up to 37,708 Baht/ rai/ year. (INBAR, 2021).

The shoot of Sri-Prachin is a popular agricultural product among domestic and international consumers. It can generate a lot of income for farmers in Prachinburi province for it yields consistent rate of shoot emergence after the 3rd year up to the 10th year of cultivation. Throughout the 10-year lifetime of Phai Tong, farmers can make a total net profit of about 506,053.69 Baht/farm/year. This represents 56.56% of the total income, with fertilizer and fuels considered the factors that contribute to high production costs, accounting for 43.12% of total costs (Patana, 1987). In addition to providing sufficient water, promoting out-of-season shoot emergence and forcing more shoots require additional resources, such as black plastic bags, urea fertilizer 46-0-0 at a rate of 0.5 kg/month/clump of bamboo, chicken manure at a rate of 15-30 kg/clump of bamboo, and herbicide use at least 2 times/year (Tancharoen *et al.*, 2015). This includes trimming, cleaning, and transporting the product to the central market. In other words, to achieve the yields, some inputs must be brought into each of the production sector, resulting in the release of waste into the environment. Therefore, assessing the carbon footprint (CF) of producing the shoot will give us an idea of any sectors with the highest level of greenhouse gas emissions so that we can try to develop guidelines to reduce energy consumption or use resources more efficiently— another way to reduce production costs. For example, the production of 1 ton of fresh pineapples releases 98.45 kgCO_2e/ton of greenhouse gases (Boonmark and Yuttitham, 2015). In growing pomelos, using chemical fertilizer (2.5604 tonCO_2e/rai) gave the carbon footprint of higher than natural fertilizer (0.0481 tonCO_2e/rai) (Chotsirikoonnawat *et al.*, 2019). The carbon footprint could be reduced by decreasing the use of chemical fertilizer and promoting the use of natural fertilizer, including the use of pesticides made from natural products. In the production of jasmine rice products, the sector that involves rice growing contributed to the highest level of greenhouse gas emissions, and the life cycle inventory of the sector varied with the amount of carbon footprint (Mangkang *et al.*, 2011). Therefore, the guidelines on reducing the carbon footprint should be taken into consideration. Carbon Footprint of Products (CFP) is defined as Greenhouse Gas (GHG) emissions of a product through its life cycle stages, including material acquisition, production, distribution, usage, and waste management at its end of life as well as relevant transportation in each stage of the product (TGO, 2012). CFP is a quantitative "measurement" of product and service impacts on the environment using the Global Warming Potential (GWP) indicator. The Intergovernmental Panel on Climate Change (IPCC) has determined the GWP value for a specified period of time (Kamnuengphol *et al.*, 2019). The sum of GHG emissions generated over the life cycle based on the scope of the study is concerned to the carbon footprint of the product or service which the carbon footprint is assessed (Boonkum, 2010). Therefore, the study aimed to evaluate the carbon footprint of producing the shoot of Sri-Prachin bamboo for commercial purposes with covering the sectors of material acquisition to transportation of the yields other products, and to evaluate the amount of greenhouse gases released as carbon dioxide equivalent (CO_2e).

Materials and methods

Determining the scope of the study

The research was focused on assessing the carbon footprint of producing the shoot of Sri-Prachin bamboo (*Dendrocalamus asper* Backer) by estimating greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are greenhouse gases resulting from main activities in the agricultural sector. It based on the Cradle-to-Gate (or Business-to-Business: B-2-B) model that involves the sectors of raw material acquisition, production, and transportation as shown in the raw material flow diagram (Figure 1). The details of the sector include soil preparation, cultivation, post cultivation care, harvesting/cutting of bamboo shoots, sorting, trimming, packing and transportation of the product from Thung Pho sub-district, Na Di district, Prachinburi province to the central market for vegetables and fruits at Pathom Mongkol Market, Nakhon Pathom Province (Figure 2). The functional unit designation was 1 ton of Sri-Prachin bamboo.

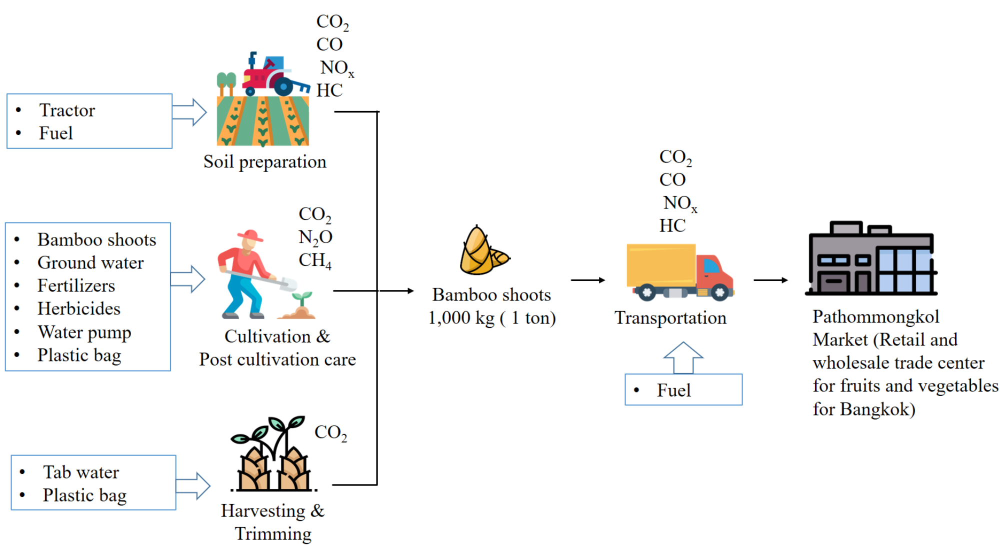

Figure 1. Raw material flow diagram and greenhouse gases resulting from main activities in the agricultural sector

Life cycle inventory data collection

The primary data were obtained from field surveys and responses to questionnaires of bamboo farmers who commercially cultivate Sri-Prachin bamboo on 10 plantations in Thung Pho sub-district, Na Di district, Prachinburi province: using a purposive sampling technique. These included the details on cultivating areas, cultivating methods, plant care, shoot storage and management, transportation etc. The secondary data were collected from bills for related services such as water use, fertilizer consumption, chemical and fuel use, etc. All data were aggregated in the life cycle inventory.

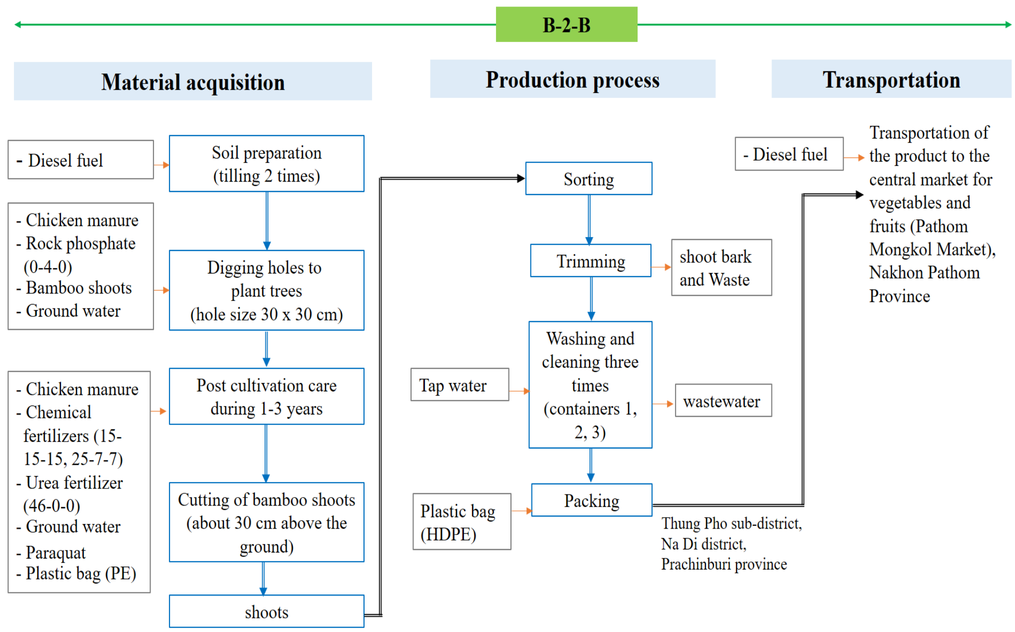

Figure 2. Scope of the study and raw material flow diagram in B-2-B model

Impact assessment

The greenhouse gas (GHG) emissions were estimated by measuring and calculating data from the activities that occured and the emission factor (EF) as proposed by Thailand Greenhouse Gas Management Organization (Public Organization: TGO, 2021) which marked as CO_2 emissions = Activity Data x EF; where CO_2 emissions, carbon footprint from any activity (kgCO_2e), activity data and EF can be calculated using Table 1.

GHG emissions from fertilizer were divided into two parts. Part 1 involved the acquisition e.g. fertilizer production (nitrogen, phosporus and potassium). The fertilizer acquisition was based on the straight fertilizer by selecting the Cradle-to-Gate database for fertilizer production (Table 2). The amount of greenhouse gas emissions resulting from fertilizer application was calculated as GHG of the fertilizer acquisition (kgCO_2e) = Fertilizer consumption (kg) x [(%N x EF) + (%P_2O_5 x EF) + (%K_2O x EF) + (%Filler x EF)] (TGO, 2021; Chotsirikoonnawat *et al.*, 2020).

Table 1. Emission factors for GHG emission inventories

Inventories in each sector	Units	EF (kgCO_2e/Unit)	Soures
1. Soil preparing & cultivation			
Chicken manure	kg	0.1097	Ecoinvent 2.0 (Econvent Centre, 2007)
Rock phosphate (0-4-0)	kg	0.0629	Ecoinvent 2.0 (Econvent Centre, 2007)[1/]
Chemical fertilizer (15-15-15)	kg	1.5083	Ecoinvent 2.0 (Econvent Centre, 2007)
Chemical fertilizer (25-7-7)	kg	2.3012	Ecoinvent 2.0 (Econvent Centre, 2007)[1/]
Urea fertilizer (46-0-0)	kg	3.3036	Ecoinvent 2.0 (Econvent Centre, 2007)
Paraquat	kg	3.2300	Ecoinvent 2.0 (Econvent Centre, 2007)
Diesel fuel	kg	0.3522	Thai National LCI Database, TIIS-MTEC-NSTDA (TGO, 2019)
Plastic bag (PE)	kg	1.5200	JEMAI Pro using Thai Electricity Grid (TGO, 2011)
2. Harvesting & trimming			
Tap water (Provincial Waterworks Authority; PWA)	m^3	0.2843	Thai National LCI Database, TIIS-MTEC-NSTDA (TGO, 2019)
Plastic bag (HDPE)	kg	6.7071	Thai National LCI Database, TIIS-MTEC-NSTDA (TGO, 2019)
3. Transportation			
Pickup truck (0% Loading)	km	0.3131	Thai National LCI Database, TIIS-MTEC-NSTDA (TGO, 2019)
Pickup truck (100% Loading)	tkm	0.1411	Thai National LCI Database, TIIS-MTEC-NSTDA (TGO, 2019)

[1/] Calculated from GHG emissions from fertilizer of product carbon footprint (TGO, 2016)

Table 2. Emission factors of straight fertilizers

Fertilizers	EF ($kgCO_2e/kg$)	Sources
Urea as N	3.3036	Ecoinvent 2.0 (Econvent Centre, 2007)
Diammonium Phosphate (DAP) as P_2O_5	1.5716	Ecoinvent 2.0 (Econvent Centre, 2007)
Potassium chloride (KCl) as K_2O	0.4974	Ecoinvent 2.0 (Econvent Centre, 2007)
Filler[1/]	Assume filler EF = 0	

[1/] A filler is used to fill the mixed fertilizer in order for the fertilizer to reach the required weight, the added substances must not react with the fertilizer materials or fertilizer nutrients. The most commonly used fillers include fine sand, sawdust or other synthetic substances.

Part 2 involved to calculate nitrous oxide (N_2O) fertilizer where 1% N was converted into nitrous oxide, calculated from nitrous oxide (kgN_2O) fertilizer = fertilizer dose (kg) x [(%N x 1/100)] x (44/28). Therefore, GHG dose ($kgCO_2e$) from fertilizer use = fertilizer acquisition GHG + fertilizer GHG (TGO, 2016; Chotsirikoonnawat *et al.*, 2020).

The methodology for human research ethics aspect was done in the field surveys and responsed to questionnaires from bamboo farmers. The ethical guidelines for human research were certified for approval from the Valaya Alongkorn Rajabhat University under the Royal Patronage Research Ethics Committee (COA No. 0042/2566).

Results

Life cycle inventory

The results of the random interviews on the sectors of raw material acquisition to transport raw materials for further production in 10 plantations of Sri Prachin bamboo shoots in Thung Pho sub-district, Na Di district, Prachinburi province showed that averaged Sri-Prachin bamboo cultivated area was 10.20 rai (1.632 ha; 1 rai = 0.16 ha) per a plantation. The bamboo planting area of 1 rai showed an average bamboo shoot yield of 1,942.6 kg and important resources were used in the production process such as 1.83 kg of diesel fuel, 21.6 m^3 of tap water, 755.83 kg of fertilizers and 2.68 kg of plastic bag. This data reources were recored the inventories in each sector. The life cycle inventory based on the Cradle-to-Gate model at the sectors of raw material acquisition to production and transportation is shown in Table 3.

Analysis results of greenhouse gas emissions

The analysis results of greenhouse gas emissions generated from producing 1 ton of Sri-Prachin bamboo shoots, based on the Cradle-to-Gate model in the form of carbon dioxide equivalent were divided into three sectors; raw material acquisition, production, and transportation. The assessment result showed that the total carbon footprint of all activities was 227.7154 $kgCO_2e$ /ton. Among these, transportation or distribution of the products from the source of production in Prachinburi province to the agricultural central market (Pathom Mongkol Market) in Nakhon Pathom province by using a 4-wheeled diesel pickup to make a headhaul shipment (100% Loading) and a backhaul shipment (0% Loading) at the total distance of 500 kilometers, under normal circumstances, produced the highest carbon footprint of 113.550 $kgCO_2e$ /ton (49.865% of CO_2 emission). This is followed by the sectors of raw material acquisition (soil preparation and cultivation) and production (trimming and cleaning yields) which produced carbon footprint at the average of 99.842 and 14.324 $kgCO_2e$/ton, respectively (Table 4 and Figure 3).

Table 3. Result of inventory analysis for bamboo shoots

Inventories in each sector	Amount	Units
1. Soil preparing & cultivation[1/]		
Bamboo branch	255	trees/rai
Chicken manure	733.37	kg/rai
Rock phosphate (0-4-0)	0.38	kg/rai
Chemical fertilizer (15-15-15)	12.75	kg/rai
Chemical fertilizer (25-7-7)	6.38	kg/rai
Urea fertilizer (46-0-0)	22.95	kg/rai
Paraquat	0.26	kg/rai
Diesel fuel	1.83	kg/rai
Plastic bag (PE)	1.46	kg/rai
2. Harvesting & trimming		
Tap water (PWA)	21.60	m^3/ton
Plastic bag (HDPE)	1.22	kg/ton
3. Transportation		
Pickup truck (0% Loading)	250	km
Pickup truck (100% Loading)	250	km/ton

[1/] Soil preparing and cultivation sectors were calculated unit/rai as Thai unit (1 rai = 1,600 square meters = 0.16 ha)

Table 4. Result of GHG emissions from 1 ton of bamboo shoot production

Inventories in each sector	Amount	Units	EF ($kgCO_2e$/Unit)	GHG emission ($kgCO_2e$)
1. Soil preparing & cultivation				
Chicken manure	377.606	kg	0.1097	41.4234
Rock phosphate (0-4-0)	0.196	kg	0.0629	0.0123
Chemical fertilizer (15-15-15)	6.565	kg	1.5083	9.9018
Chemical fertilizer (25-7-7)	3.285	kg	2.3012	7.5595
Urea fertilizer (46-0-0)	11.817	kg	3.3036	39.0379
Paraquat	0.134	kg	3.2300	0.4324
Diesel fuel	0.942	kg	0.3522	0.3319
Plastic bag (PE)	0.752	kg	1.5200	1.1426
2. Harvesting & trimming				
Tap water (PWA)	21.60	m^3	0.2843	6.1409
Plastic bag (HDPE)	1.22	kg	6.7071	8.1827
3. Transportation				
Pickup truck (0% Loading)	250	km	0.3131	78.2750
Pickup truck (100% Loading)	250	tkm	0.1411	35.2750
Total carbon footprint ($kgCO_2e$/ton)				227.7154

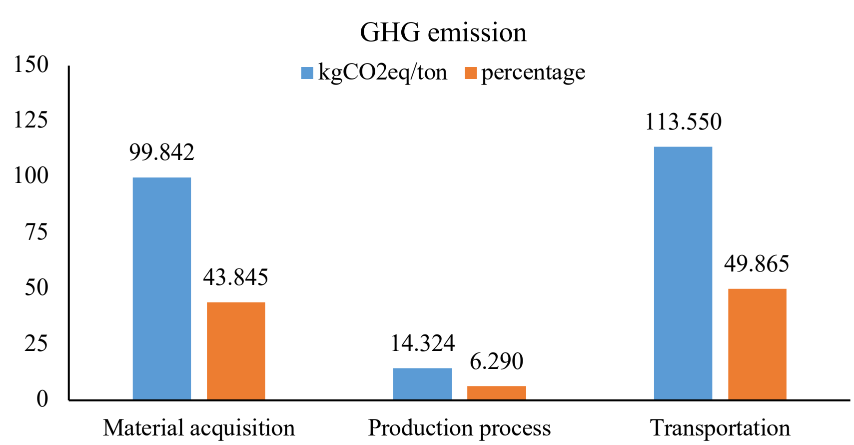

Figure 3. GHG emission and precentrage of each sector: material acquisition, production process, and Transportation

Discussion

Analysis of the life cycle inventory from the material flow diagram in each sector showed that there was a variation according to the activities. For example, energy was mainly used in the sector of raw material acquisition. Urea fertilizer (46-0-0) and chicken manure with chemical fertilizer formulae (15-15-15 and 25-7-7) were also used during the sectors of shoot development and increased nutrient requirements for bamboo growth. The bamboo required high nitrogen content during the yield period. In addition, the widely use of organic fertilizer with chemical fertilizer supports bamboo to absorb nutrients completely and consistency in shoots while reducing atrophy or dormancy (INBAR, 2021; Deerassamee, 1999; Poomtabtim, 2019). The other chemical fertilizer formulae such as 16-16-16 and 13-13-21 were also used. The choice of fertilizer application is varied according to economic conditions, however it mostly depended on suggestions of the community leaders (Tisawat and Kalyasilapin, 2021).

The greenhouse gas (GHG) emission was generated from various activities. Specifically in the sector of cultivating bamboo to produce shoots, the second-highest level of GHG emissions was found at 99.842 kgCO2e/ton, or as 43.845% of total CO_2 emissions. In the cultivation, farmers used two types of fertilizer which were organic fertilizer (chicken manure) and chemical fertilizer. The phosphate rock (0-4-0) was then mixed together to used as fertilizer which covering at planting holes before planting. The chicken manure was the most activity with GHG emissions at 41.4234 kgCO_2e/ton. The applied chemical fertilizers formulae, 46-0-0, 15-15-15 and 25-7-7, led to GHG emissions at 56.9439 kgCO_2e/ton, or as 24.811 % of CO_2 emission. The 46-0-0 fertilizer formula has the highest GHG emissions at 39.0379 kgCO2e/ton and the 15-15-15 fertilizer formula has the lowest GHG emissions at 7.5595 kgCO_2e/ton. GHG emissions from chicken manure were lower because it has a lower emission factor than the 3 chemical fertilizer formulae (Table 4). This result means that GHG emissions from the use of chemical fertilizer were due to the acquisition of chemical fertilizer which was much different from that of natural fertilizer (Chotsirikoonnawat *et al.,* 2019). A comparison between the use of chicken manure and chemical fertilizer showed that the use of chemical fertilizer has a higher GHG emission value than the use of chicken manure. It means that GHG emissions from the use of chemical fertilizer were due to the acquisition of chemical fertilizer which was much different from that of natural fertilizer (Chotsirikoonnawat *et al.,* 2019). Whereas the herbicidal chemical, it was used in the raw material acquisition sector. Based on the data gained from agricultural seminars, paraquat was applied twice a year, resulting in GHG emissions at

0.4324 kgCO_2e/ton, or as 0.190% of CO_2 emission. In this sector, manufactured plastic bags from polyethylene (PE) were also used to wrap the bamboo shoots, resulting in GHG emissions at 1.1426 kgCO_2e/ton, or as 0.502 % of CO_2 emission. According to the results, it can be concluded that GHG emissions during the sector of raw material acquisition were mainly from fertilizer application, especially chemical fertilizer. It was consistent with the studies of Boonmark and Yuttitham (2015) and Chotsirikoonnawat *et al.* (2019) which was found that GHG emissions from agricultural areas were mainly due to the use of chemical and organic fertilizers. Therefore, suggestions and guidelines to consider for reducing GHG emissions in the sector of raw material acquisition are that farmers should adjust their cultivation methods by reducing the use of chemical fertilizer and increasing more organic fertilizer in their cultivation, or alternated chemical fertilizer with a low emission factor should be adapted to replace or combine. For example, decreasing the using of 46-0-0 chemical fertilizer and replacing or mixing it with 16-16-16 chemical fertilizer. It would then have an emission factor at 0.7493 kgCO_2e/unit (TGO/EF, 2021; Sriapai and Phoochinda, 2021) which is lower than the using of 46-0-0 chemical fertilizer only. Moreover, the application of 16-16-16 chemical fertilizer resulted in the highest number of emerging bamboo shoots. It was probably because the fertilizer was full of nutrients and sufficient for the requirements, resulting in a nutrient balance. This formula effectively stimulates the generation of new shoots, resulting in a larger size of bamboo shoot when compared to the 46-0-0 chemical fertilizer (Vacharotayan *et al.,* 1998). In addition, farmers are recommended to use chemical fertilizer 15-15-15 in combination with chicken manure as a replacement for chemical fertilizer 25-7-7. The reason could be that 15-15-15 chemical fertilizer had an emission factor at 1.5083 kgCO2e/unit, which was lower than that of 25-7-7 chemical fertilizer. Moreover, it resulted in a high and consistent rate of shoot emerging. It was also found that the average diameter and sugar content of the Sri-Prachin bamboo shoots were greater when compared to the using of 25-7-7 chemical fertilizer (Tisawat and Kalyasilapin, 2021). The quality of the soil was varied on properties of the field, as a consequence, the fertilizer formulae or the amount of fertilizer applied sould be adjusted to be appropriate for specific areas. Therefore, farmers should study the soil properties of their fields so that they can choose the appropriate fertilizer formula for the area. The good yields would then be obtained while reducing costs and, more importantly, reducing GHG emissions from fertilizer use in the area. According to the approach reducing the use of herbicides, farmers are advised to choose natural herbicides, to use mechanical control approaches, or to cover the field with natural materials such as planting bean; a cover crops, such as jack bean or house bean to reduce the use of herbicides during the rainy season

(May-June) before cutting them down as fresh plant fertilizer (Tisawat and Kalyasilapin, 2021).

For plastic bags section, even though it has a usage volume of only 1.22 kg, they should be considered to be used at the maximum benefit because it would help to reduce GHG. The production sector showed the lowest GHG emission value at 14.324 $kgCO_2e$/ton, or as 6.290% of CO_2 emission. The bamboo shoots were collected after harvesting, starting from the trimming, washing, cleaning, and packing. The input lists included pipe water at 21.60 m^3 and 1.22 kg of 20x30 HDPE plastic bags. The production sector resulted in GHG emissions of 14.324 $kgCO_2e$/ton, representing 6.290 % of CO_2 emissions (Figure 3). Considering the activity, it was found that the use of plastic bags containing bamboo shoots could generate GHG emissions of 8.1827 $kgCO_2e$/ton which was considered higher than the use of large quantities of water. For examples, farmers washed and cleaned the shoots in three 3x2x1.2 m cement wells containing 7.2 m^3 volumes of water, producing GHG emissions equal to 6.1429 $kgCO_2e$/ton. This result shows that plastic bags had the greatest GHG emission factor from all life cycle inventories at 6.7071 $kgCO_2e$/unit (Thai National LCI Database, TIIS-MTEC-NSTDA, TGO, 2021), even with the usage amount of only 1.22 kg. Therefore, in this production sector, the maximum utilization of plastic bags should be considered.

The sector of transportation was found to have a high GHG emissions level at 113.550 $kgCO_2e$/ton, or as 49.865% of CO_2 emission. The source of GHG emissions comes from the use of diesel fuel in small 4-wheel pickup trucks to transport a total volume of 60 liters. Therefore, the suggestion and guideline to consider for reducing GHG emissions is that vehicle users should well prepare before traveling, always maintain the engine, and drive properly.

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