Life Cycle GHGs and Particulate Matters Emissions Evaluations of Maize Cultivation in Chiang Dao, Chiang Mai

Titaphorn Supasri[1], Panich Intra[2] and Sate Sampattagul[1,*]

[1]*Center of Excellence on Energy, Economic and Ecological Management (3E), Science and Technology Research Institute, Chiang Mai University, Chiang Mai 50200, Thailand*
[2]*Research Unit of Applied Electric Field in Engineering (RUEE), College of Integrated Science and Technology, Rajamangala University of Technology Lanna, Chiang Mai 50220, Thailand*
**Corresponding author. Tel.: +66-53-942086, Fax: +66-53-944126, E-mail address: sate@eng.cmu.ac.th*

Abstract: The goal of this study was to provide an assessment of life cycle greenhouse gas emissions and particulate matters emissions of maize by using a Life Cycle Assessment (LCA). The focus study area is Chiang Dao district in Chiang Mai province. The system boundary (from cradle-to-farm gate) is starting from land preparation and continuing through cultivation and the harvesting process. The functional unit of this study was 1 kg of maize yields at farm gate. As for the results, the total greenhouse gas emissions from maize production in Chiang Dao district is equal to 9,621.397 tonnes CO_2 eq while particulate matters emissions are equal to 85.877 tonnes PM10 eq. The single largest source of greenhouse emissions occurred during the field emission process at about 45.64%, The next largest is planting process contributed 23.60%, followed by open burning and fertilizer use processes contributed 16.68% and 13.30%, respectively. Particulate matters emissions were found during the process of cultivation at about 69% and in the open burning and harvesting processes at approximately 31% and 0.18%, respectively. This study can be used to lead the development of new guidelines and indicates opportunities for further improvement in the best practices of agriculture in the northern area of Thailand for the sustainable production and consumption of maize for the future.

Keywords: Maize, Life Cycle Assessment, Greenhouse gas, Particulate matters, Air pollution.

1. Introduction

Maize in Thailand is predominantly used for animal feed, with 80-100% of production being sold to commercial livestock feed mills. Maize sold as animal feed is mainly used domestically, and only a small fraction is exported. The maize demand in Thailand for the year 2015 was 5.34 million tons, a slight increase of 5.95% from the year 2014, due to the increase in demand of feed industry and expansion of livestock industry [1]. Thus, the mountains of grain needed to produce animal feed have caused more than 12 million rais of agricultural and forest land to be cleared for maize farming [2]. The current farming practices of maize have also caused several problems to local communities as well as urban dwellers, such as widespread clearing of forestlands has led to flooding and landslides resulting in road accidents and crop damage. In addition, the excessive use of chemical fertilizers and pesticides which has caused environmental impacts and open burning of maize residues after harvesting has caused air pollution and haze affecting health in northern Thailand.

The literature review disclosed many researchers that have reported the valuable application of LCA model in environmental management of agricultural production. Some studies have been conducted in terms of environmental impacts assessment during maize farming activities, for example Grant and Beer (2006) evaluated the environmental impact of the greenhouse gas emissions of pre-farm, on-farm and post-farm activities involved in the use of maize for the manufacture of corn chips [3]. The biggest sources of greenhouse gas emissions were post-farm activities which accounted for about 68% of life-cycle greenhouse gas emissions. In later work, Li et al. (2007) determined particulate emissions and trace gas emissions from open burning of wheat straw and maize cob [4]. They found the PM2.5 emission factors of wheat straw and maize cob are 7.6 g/kg and 11.7 g/kg, respectively. Recently, Kim at al. (2014) studied and compared quantitatively and qualitatively 21 published life cycle assessments for energy consumption and greenhouse gas emissions of maize production in the USA [5]. GHG emissions associated with maize production range from −27 to 436 g CO_2 eq per kg of maize.

Regarding the previous literature review, there were only greenhouse gas evaluations of maize farming; no previous analytical work had been reported on the deeply particulate matters emission evaluation from maize farming in northern Thailand. Therefore, the aim of the study was to provide an assessment of life cycle greenhouse gas emissions and particulate matter emissions of maize by using a Life Cycle Assessment (LCA).

2. Experimental

2.1 Site of study and maize cultivation

This study focused on maize farming in Chiang Dao district. Chiang Dao is a district located in the north of Chiang Mai province in northern Thailand. Geographically, it lies between the 19°21′58″N 98°57′51″E / 19.36611°N 98.96417°E and covers an area of 1,882.1 km^2. Most of the terrain in Chiang Dao district is covered by upland areas. According to Department of Agricultural Extension in 2015 [6], maize production in Chiang Dao district is about 21,769 tonnes while the commodity price of maize is 8.58 baht per kilogram. By these reasons, maize farming is tremendous growing. However, due to the lacking of labor and cost reduction by poor farmers, the open burning in Chiang Dao district is widely used in order to get rid of maize cob and husks because it is the fastest way and cost saving in harvesting and land preparation. Therefore, by this malfunction and improper ways of agriculture, it has been contributed to global warming and haze problems and increased every year.

In Chiang Dao district, the first crop of maize is usually grown in May. Land preparation and sowing begins in April/May after the first rain. Land preparation consisted of land clearing, burning crop residues, and tillage by tractors. Land clearing and burning of crop residues were often done in February to March, and tillage was mostly done in April, just before sowing. Finally, farmers harvest their product dry in the fields in either December or January. The study area is shown in Fig. 1.

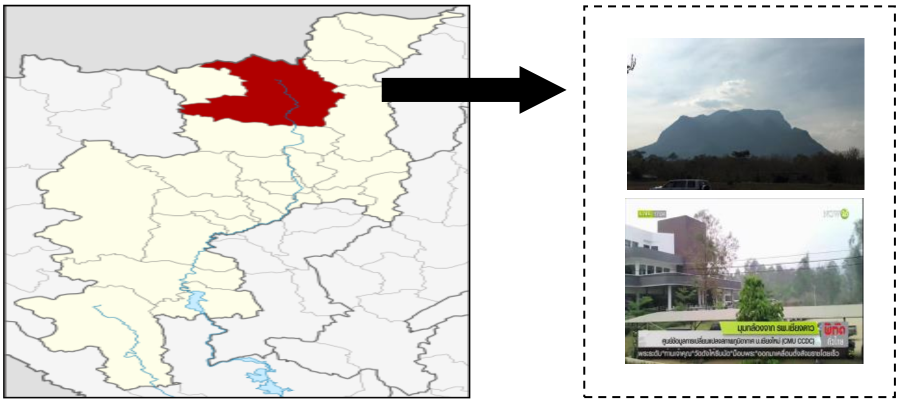

Figure 1. Map of Chiang Dao district in Chiang Mai Province.

2.2 Goal and Scope

The aim of this study was to provide an assessment of life cycle greenhouse gas emissions and particulate matters emissions of maize by using a Life Cycle Assessment (LCA). The functional unit (FU) of this study is connected to the inputs and outputs and provides a condition for comparison, which is usually equivalent to 1 kg of maize yields at farm gate.

2.3 System boundary

The system boundary (from cradle-to-farm gate) is starting from land preparation and continuing through cultivation processes (planting, weeding and fertilizer use processes), followed by the harvesting process and the last process is post harvesting (open burning). First, the inputs include herbicides, maize seeds, fertilizers, pesticides, diesel and transportation. The system outputs contained all of the pollutants emitted to the environment and were calculated out of using these inputs based on a functional unit. We calculated the greenhouse gas emissions factor for maize cultivation including CO_2, CH_4 and N_2O. For the particulate matters emissions including NO_x, SO_x, NH_3, PM10 and PM2.5 [7]. Fig. 2 shows all of the inputs and outputs for maize production in Chiang Dao district.

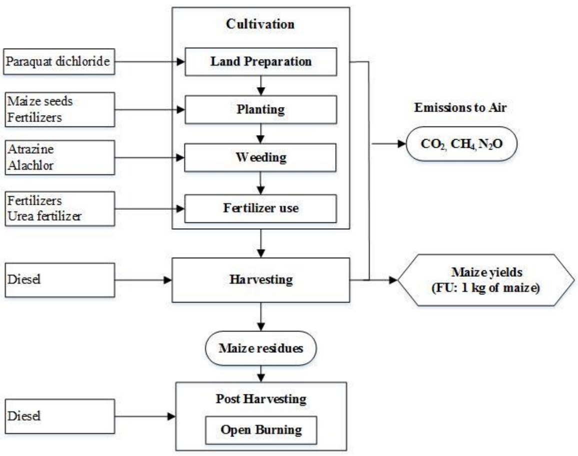

Figure 2. System boundary of maize cultivation.

2.4 Data sources and inventory

The data sources of maize cultivation were used Department of Agricultural Extension, Chiang Dao district. The calculations and assumptions of inventory were identifiable based on secondary data. According to Department of Agricultural Extension in 2015 [6], maize harvested area is about 38,325 rais and the open field burning in Chiang Dao district is about 47,602 rais. Maize production in Chiang Dao district is about 568 kg per rai while the maize cob is 135 kg per rai, calculate by the ratio of biomass and maize yields from Department of alternative energy development and efficiency [8]. The inventory inputs and outputs of maize cultivation are mentioned in Table 1.

Table 1 Inventory input of maize cultivation

Maize cultivation stage	Input	Quality	Unit
Land Preparation	Paraquat dichloride	0.15	kg rai^{-1}
Planting	Maize seed	3.00	kg rai^{-1}
	Organic fertilizer	150.00	kg rai^{-1}
	Fertilizer 15-15-15	50.00	kg rai^{-1}
Weeding	Atrazine	0.38	kg rai^{-1}
	Alachlor	0.50	kg rai^{-1}
Fertilizer use	Fertilizer 21-0-0	30.00	kg rai^{-1}
Harvesting	Diesel	0.85	kg rai^{-1}
Maize cultivation stage	**Output**	**Quality**	**Unit**
Harvesting	Maize yields	568.00	kg rai^{-1}
Post Harvesting	Maize cob	130.00	kg rai^{-1}

Regarding the data collection, it was found that 7-ton trucks were used to transport raw materials. We assumed the distances roughly 10 km (round-trip). We noted that organic fertilizer from hence do not need to be transported.

2.5 Evaluation of GHGs and particulate matters emissions

The LCA process is carbon accounting, except it can be used to evaluate a larger number of emissions and impact factors using a life cycle approach. The guiding principles of an LCA follow the International Organization for Standardization (ISO) standards ISO 14040 and ISO 14044 [9-10]. These two ISO standards provide an overview of the steps of an LCA: (1) Goal and Scope Definition (2) Life Cycle Inventory Analysis (3) Life Cycle Impact Assessment and (4) Interpretation. [11].

This study is to assess the processes of maize farming to identify the greenhouse gas emissions and particulate matters emissions of maize. A more cost-effective approach may be to identify the major emission sources that are amenable to greenhouse gas mitigation. An LCA can be employed for carbon accounting and used to evaluate other critical environmental impacts, such as acidification, ozone depletion, eutrophication, smog and human health effects. The GHG emission factors of raw materials and other inputs relevant to this study from [12]. In this study, we used the total greenhouse gas emission factor for agricultural waste burning is 1,501.72 kg per kg maize cob from Li et al. (2007). The GHG emissions from inputs for maize cultivation were calculated by a given equation [13].

$$GHG_R = A_i \times EF_i \tag{1}$$

Where GHG_R is the amount of GHG emissions from using raw materials/other inputs (kg CO_2 eq), A_i is activity data in the unit of raw materials/other inputs (such as kg and litre), EF_i is the GHG emissions factor of raw materials/other inputs (kg CO_2 eq/unit of input) and i is refer to the type of raw materials/other inputs.

GHG emissions from transport of raw materials for maize cultivation practice were calculated by a given equation (2) [12].

$$GHG_T = \sum (W_i \times D_i \times EF_T) \tag{2}$$

Where GHG_T is amount GHG emissions from raw material transport (kg CO_2 eq), W_i is weight of raw material (ton), D_i is transportation distance (km) and EF_T is emission factor of transportation by 7-ton truck (0.1824 kg CO_2 eq/tkm)

GHG emissions from maize field include direct air emissions of nitrous oxide (N_2O) from the application of nitrogen (N) in land preparation, planting and fertilizer use processes. Evaluation of maize fields emissions in the study include direct N_2O and indirect N_2O which occur from volatilisation, leaching and runoff of N input. The total of N_2O emissions (direct and indirect N_2O emissions) from maize fields were calculated by a given equation [13].

$$Total\ N_2O\ emission = N_2O_{Direct} + N_2O_{Indirect} \tag{3}$$

Finally, N_2O emissions (in kgN/year) from maize fields were an estimation of GHG emissions (in CO_2 eq).

The particulate matters emissions factors of raw material inputs from ReciPe in SimaPro programme [14]. We calculated the total particulate matters emissions factor for agricultural waste burning is 13.40 kg per kg maize cob [7]. Particulate matters emissions from maize cultivation were calculated by a given equation (4)

$$PM10_R = A_i \times PMF_i \tag{4}$$

Where $PM10_R$ is the amount of particulate matters emissions from using raw materials/other inputs (kg PM10 eq), Ai is activity data in the unit of raw materials/other inputs (such as kg and litre), PMF_i is the particulate matters emissions factor of raw materials/other inputs (kg PM10 eq/unit of input) and i is refer to the type of raw materials/other inputs.

3. Results and Discussion

3.1 Total GHG emissions from maize cultivation

Fig. 3 illustrates the amounts of emitted pollutants from the consumption of inputs and activities for production of one kg of maize in Chiang Dao district. As a result, the single largest source of greenhouse emissions is the field emission process at 0.974 kg CO_2 eq per kg of maize, followed by planting process contributed 0.798 kg CO_2 eq per kg of maize, open burning, fertilizer use, weeding, harvesting and land preparation processes contributed 0.356, 0.284, 0.010, 0.005 and 0.001 kg CO_2 eq per kg of maize, respectively.

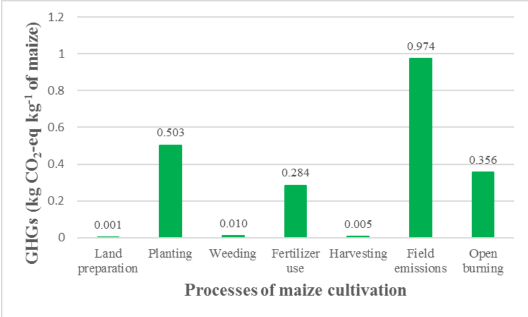

Figure 3. Life cycle greenhouse gas emissions of maize cultivation per 1 kg maize.

Fig. 4 illustrates the amounts of emitted pollutants from the maize field that include land preparation, planting and fertilizer use processes. As a result, the GHG emissions occurred during the planting process at about 0.776 kg CO_2 eq per kg of maize, fertilizer use and land preparation contributed 0.132 and 0.066 kg CO_2 eq per kg of maize, respectively.

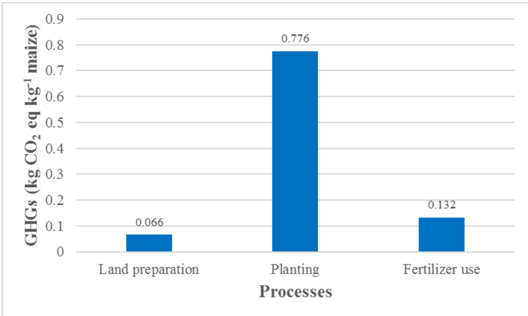

Figure 4. Field emissions of maize cultivation per 1 kg maize.

3.2 Total particulate matters emissions from maize cultivation

Fig. 5 shows the amount of particulate matters emissions from the entire life cycle of maize production. The result was found during the process of weeding at about 6.762 g PM10 eq per kg of maize and in the open burning, planting, fertilizer use, harvesting and land preparation processes at approximately 3.176, 0.227, 0.059, 0.018 and 0.010 g PM10-eq per kg of maize, respectively.

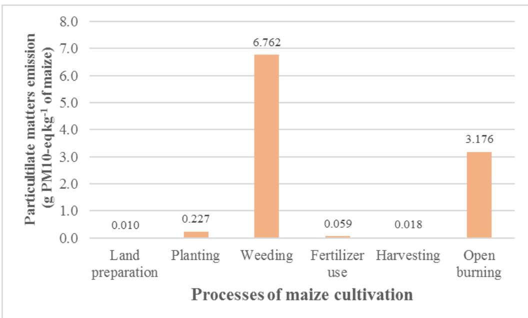

Figure 5. Life cycle particulate matters emissions of maize cultivation per 1 kg maize.

We compared the GHGs and particulate matters emissions from open field burning between Chiang Dao and Mae Chaem districts. According to the previous study Supasri et al. (2016), open field burning in Mae Chaem district was about 70,953 rais, the total greenhouse gas and particulate matters emissions from maize production in Mae Chaem district is about 26,719.481 tonnes CO2 eq and 238.230 tonnes PM10 eq, respectively [15]. While open field burning in Chiang Dao district was about

47,602 rais [6]. The total greenhouse gas and particulate matters emissions from maize production in Chiang Dao district is about 9,621.397 tonnes CO_2 eq and 85.877 tonnes PM10 eq, respectively. Thus, Mae Chaem district has more significant effects than Chiang Dao district because Mae Chaem district has more open field burning than Chiang Dao district.

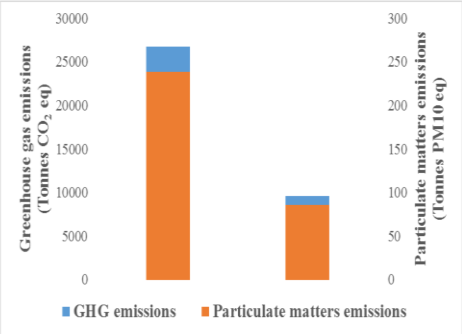

Fig.6. Comparison of GHGs and particulate matters emissions for open field burning between Mae Chaem and Chiang Dao district.

4. Conclusion

In conclusion, the total greenhouse gas emissions from maize production in Chiang Dao district is equal to 9,621.397 tonnes CO_2 eq while particulate matters emissions are equal to 85.877 tonnes PM10 eq. The largest source of greenhouse emissions occurred during the field emissions process (land preparation, planting and fertilizer use processes) at about 45.64%, The next largest is planting process contributed 23.60%, followed by open burning and fertilizer use processes contributed 16.68% and 13.30%, respectively. Particulate matters emissions were found during the process of cultivation at about 69% and in the open burning and harvesting processes at approximately 31% and 0.18%, respectively. The results of this study used to lead to new guidelines in the best practices of agriculture in the northern area of Thailand to be environmentally friendly for the sustainable production and consumption of maize for the future.

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