

## Assessment of Landuse Change and Climate Change on Runoff in Mae Chaem Watershed

การประเมินผลกระทบจากการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินภายใต้  
การเปลี่ยนแปลงสภาพภูมิอากาศต่อปริมาณน้ำท่า ในลุ่มน้ำแม่แจ่ม

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### ABSTRACT

The purpose of this study is to study the effect on runoff from the change of landuse under A2 and B2 climate scenario in Mae Chaem watershed by using SWAT model. To run SWAT various input data are required, Digital Elevation Model: DEM, climatology data, soil data, and landuse/land cover. The reliability of a simulated value shall be compared with an observed value via Coefficient of determination ( $R^2$ ) and Nash-sutcliffe efficiency ( $E_{ns}$ ). This study is divided into 3 cases which are a. Present landuse, b. A huge agriculture expansion and c. Reforestation. The result shows that among these 3 cases the most area cover with agriculture area provides the most runoff in Mae Chaem watershed.

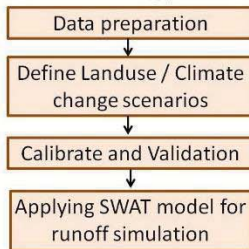
### Introduction

Since the habits of Thai's farmers have changed due to the highly competition in the present, from a Simultaneous Cropping System to a Single Crop Yields (OAD, 2010).An expansion of hill agriculture has led to more and more deforestation. Hence, either drought or flood may occur. There are other factors that can drift the behavior of water such as climate changes, and land use changes. SWAT model has been used to simulate surface runoff and also simulate the impact on surface runoff from landuse change, and climate change (SWAT, 2017).

### Objective

The aim of this study is to assessing the amount of runoff in Mae Chaem watershed in accordance with landuse change scenarios under A2 and B2 climate scenario.

### Methodology



### Result

Calibration and validation data is a monthly observed runoff from hydrology station P14A during January – December 2014 and 2016 for validation. SWAT parameters were adjusted via SWAT-CUP. Landuse change scenarios and climate change scenarios were combined to simulated runoff.

### Outcome

Achieving a fundamental runoff data for policy-makers to manage and preserve Mae Chaem watershed optimally.

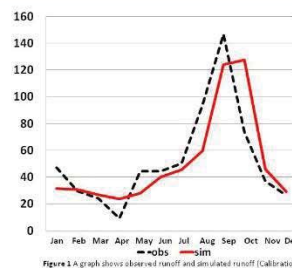


Figure 1 A graph shows observed runoff and simulated runoff (Calibration)

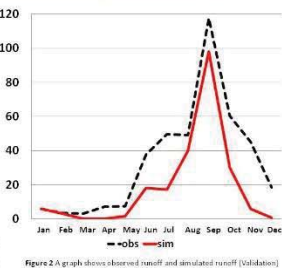


Figure 2 A graph shows observed runoff and simulated runoff (Validation)

Table 1 Parameters adjusted in SWAT-CUP

Parameters	Old Value	New Value
CN2	77	85.316
ALPHA BF	0.48	0.006
GW DELAY	31	500
GWQMN	1000	1.95

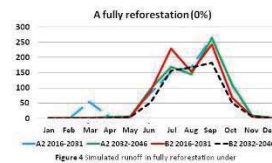


Figure 4 Simulated runoff in full reforestation under A2 and B2 climate change scenarios

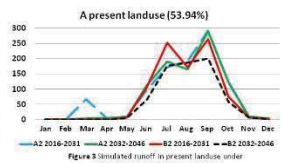


Figure 3 Simulated runoff in present landuse under A2 and B2 climate change scenarios

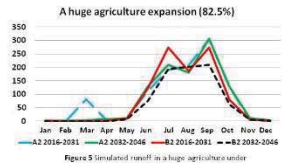


Figure 5 Simulated runoff in a huge agriculture expansion under A2 and B2 climate change scenarios

### Conclusion

Both coefficient of determination ( $R^2$ ) and nash-sutcliffe efficiency ( $E_{ns}$ ) reached the satisfactory at 0.67 and 0.65 for calibration, and 0.86 and 0.62 for validation. The evaluation from each landuse change scenario reveals that, a huge agriculture expansion scenario generate the most annual runoff (1043.78) while a reforestation scenario generate the least annual runoff (856.39)

Reference  
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SWAT: Soil Water Assessment Tool (Online). Retrieved August 7, 2017. From <http://swat.tamu.edu/>; 2017

Article

# Air-Pollutant Emissions from Agricultural Burning in Mae Chaem Basin, Chiang Mai Province, Thailand

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Received: 20 February 2018; Accepted: 10 April 2018; Published: 13 April 2018



**Abstract:** Particulate pollution is a continual problem which is usually caused by the burning of crop residues in highland agricultural systems. The objectives of this study are to investigate crop-residue management and estimate the amount of pollutant emissions from burning crop residues for each land-use pattern (grain maize, seed maize and integrated farming), and to estimate the chemical compositions of PM<sub>2.5</sub> emissions from agricultural burning in Mae Chaem basin, Chiang Mai Province, Thailand. The purposive sampling method was used for sample selection. A door-to-door questionnaire survey was used to obtain responses from 149 respondents. Greenhouse gas (GHG) emissions from the open burning of crop residues were estimated, using specific emission factors obtained from several literature reviews and from the field by the questionnaire survey. Results revealed that the majority of farmers burned maize residues during April and May and mostly in the afternoon. These burning behaviors are in line with the supportive weather conditions that reflect high values of temperature and wind speed, and less rainfall and relative humidity result in maize residues being burned easily and quickly. The integrated farming system generated the lowest GHG emissions and amount of chemical composition of PM<sub>2.5</sub> emissions, followed by the grain maize and seed maize patterns, respectively. This study strongly supports the implementation of the integrated farming system in Mae Chaem basin. Proactive and reactive measures should be taken in a well-organized and systematic fashion and should engage all related parties. More importantly, there is an urgent need for policy makers to include PM<sub>2.5</sub> concentrations to upgrade Thailand's air-quality index (PM<sub>2.5</sub> AQI).

**Keywords:** Mae Chaem basin; maize; burning crop residues; PM<sub>2.5</sub> emissions; integrated farming system

## 1. Introduction

Biomass burning is a common phenomenon across the globe that has played a vital part in worsening the climate [1]. Many studies have illustrated the amounts of biomass being burnt from various sources, including deforestation, shifting cultivation, forest fires and burning of fuel as well as agricultural residues, most of which occur in the tropical zone [2–4]. At the global scale, forest fires are the largest source of greenhouse gas (GHG) emissions as they release large amounts of carbon at one time, accounting for approximately 2020 Tg (25% of all the burnt biomass), while the second largest source is the burning of agricultural residues [5–7]. Burning agricultural or crop residues has resulted in serious air pollution in many countries and over 50% of the black carbon in the global atmosphere [8]. Particulate matter (PM) that results from biomass burning also has negative effects on both the environment and human health. In the developing world, especially in South-East Asia, open biomass burning is a common activity that typically takes place before and after cultivation as a way of controlling crop residues and weeds [9,10]. Specifically, PM<sub>2.5</sub> particles with an aerodynamic

size of less than 2.5  $\mu\text{m}$  can be deposited primarily in the pulmonary region [11,12]. Due to the large surface area of  $\text{PM}_{2.5}$ , toxins, including polycyclic aromatic hydrocarbons (PAHs) and heavy metals, are absorbed onto the surface. This can trigger or exacerbate conditions such as asthma, emphysema, bronchitis, silicosis and lung cancer [13].

In the northern part of Thailand, particulate pollution has been a recurrent problem mainly caused by burning of agricultural residues in highlands where maize is grown for animal feed. In Thailand, maize is produced mainly for animal feed: most of the maize production (80–100%) is sold to animal feed factories for commercial purposes and for domestic consumption. Only a small amount of the maize production is exported. In 2015, Thailand's domestic demand for maize was 5.34 million tons, which was a slight increase (around 5.95%) from 2006, because of the growing demand from the animal feed industry and the expansion of the livestock industry [14]. As a result, the maize-producing areas in the highland were expanded and a total amount of more than 12 million rai (1,920,000 hectares) of agricultural area and forest was turned into maize farms [15]. Farmers usually choose to burn crop residues, as burning is a quick and easy way of getting rid of them to prepare for the next cultivation season. However, burning of such biomass often releases significant amounts of air pollutants such as  $\text{CO}_2$ ,  $\text{N}_2\text{O}$ ,  $\text{CH}_4$ ,  $\text{CO}$ ,  $\text{NH}_3$ ,  $\text{NO}_x$ ,  $\text{SO}_2$ , NMHC, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and  $\text{PM}_{10}$  (particles with aerodynamic size less than 10  $\mu\text{m}$ ) [16]. Turning forest and agricultural areas into maize farms also leads to further problems such as pervasive invasions into forests, which result in floods, landslides, and subsequent road accidents as well as damage to crops. Mae Chaem basin is one area in northern Thailand that has changed the use of land from other crops and forests to grow maize significantly [17]. In addition, the overuse of chemical fertilizers and pesticides always has an impact on the environment and the burning of maize residues is a major cause of air pollutants and particulate pollution [18].

Recently,  $\text{PM}_{2.5}$  has become a major threat to people's health in Thailand and the government is placing more emphasis on the monitoring and improvement of local and regional air quality. Khamkaew et al. [19] found that the average  $\text{PM}_{2.5}$  concentrations at Chiang Mai University and Doi Ang Khang stations were  $74.5 \pm 43.5$  and  $59.1 \pm 44.1 \mu\text{g m}^{-3}$ , respectively, and confirmed that biomass burning was a major source of  $\text{PM}_{2.5}$  at both sites. Moreover, Greenpeace [20] reported that Chiang Mai province was one out of five cities with the highest annual average concentrations of  $\text{PM}_{2.5}$  from January to July 2016. Seven out of 11 cities measured (63.6%) did not reach the National Ambient Air Quality Standard, which puts the annual limits at  $25 \mu\text{g m}^{-3}$  for  $\text{PM}_{2.5}$ , and all 11 cities measured did not reach the World Health Organization (WHO) guideline annual limit of  $10 \mu\text{g m}^{-3}$ . Therefore, the objectives of this study are (1) to investigate the management of crop residues and to estimate the amounts of GHG emissions from burning crop residues of each land-use pattern: grain maize, seed maize and integrated farming; and (2) to estimate the chemical composition of  $\text{PM}_{2.5}$  emissions from agricultural burning.

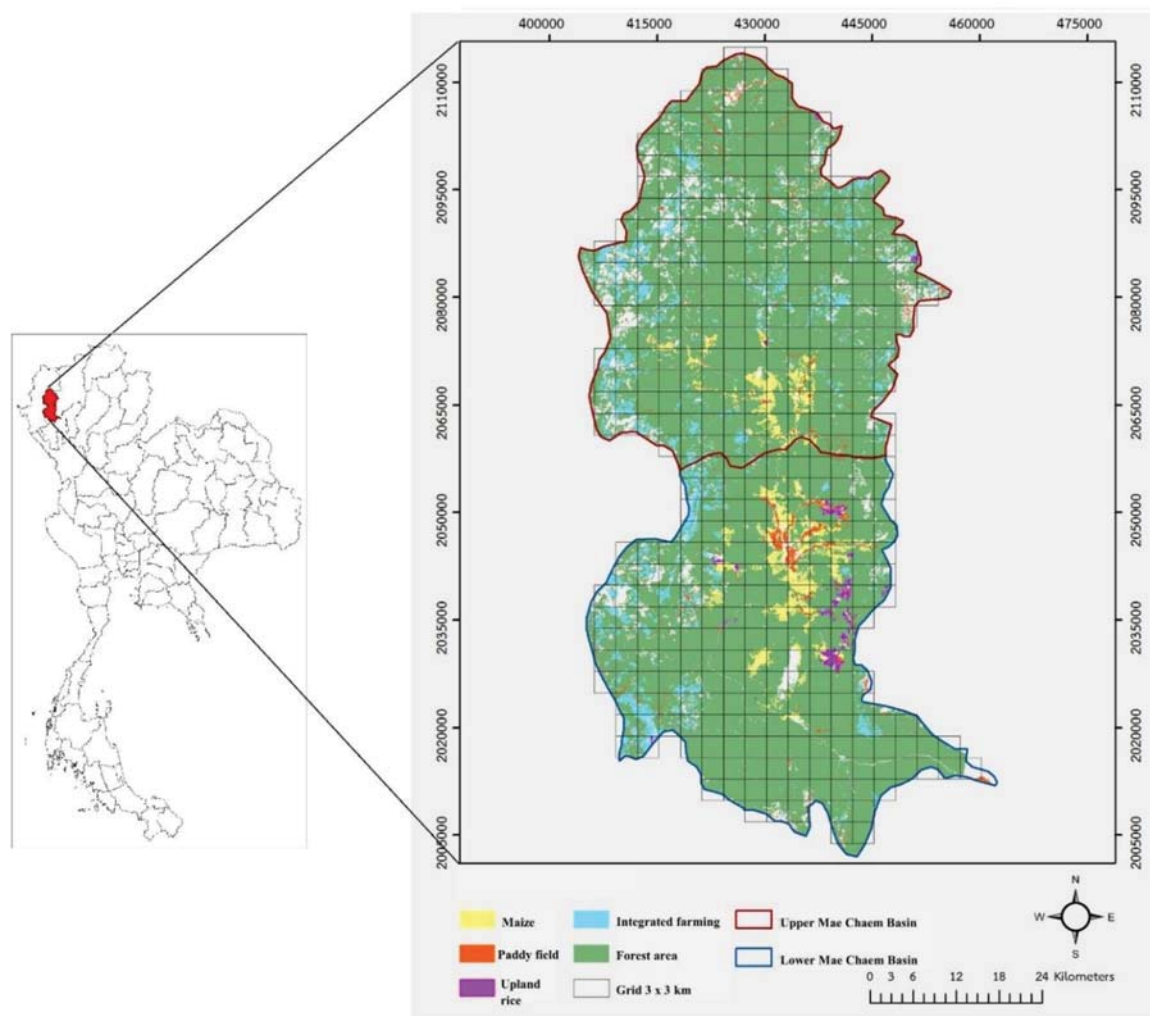
## 2. Materials and Methods

### 2.1. Study Area

The study area is Mae Chaem (Chaem River) basin, which is located in Chiang Mai Province in the northern part of Thailand. It is a tributary to the north of the Ping River, which is the largest tributary of the Chao Phraya River in the central part of Thailand. The location of the Mae Chaem basin is  $18^\circ 6' 0''$  to  $19^\circ 10' 0''$  N and  $98^\circ 4' 0''$  to  $98^\circ 34' 0''$  E, covering an area of 3853  $\text{km}^2$  (Figure 1). The climate of this area is determined by the amount of seasonal precipitation, given that the annual precipitation is influenced by Pacific-born typhoons and superimposed on the south-west monsoon [21]. These geographic parameters result in the spatial distribution of precipitation [22], an average annual temperature between 20–34  $^\circ\text{C}$ , and a rainy season that lasts from May to October.

The pattern of land use has shifted drastically over the past decades. In the 1960s, much of the plantation area at high altitude (>1000 m.a.s.l.) was dedicated to opium plantations, while at medium

altitude (600–1000 m.a.s.l.), farmers carried out rotational farming, meaning that they grew their crops for a decade and then left the land empty for another decade. The main crop grown was rice, mostly around residential areas [23,24]. In the 1980s, the Mae Chaem basin development projects led to the development of infrastructure and the promotion of small agricultural projects for commercial purposes with the aim of fighting poverty and encouraging the cultivation of other crops over opium. The development project resulted in an increasing number of agricultural products from the highlands, such as cabbage and carrots, and the expansion of industrial crops such as soybean and maize around basins between high and medium altitudes, as well as the expansion of irrigated areas for rice, fruit and orchids [23–26]. However, in the last 10 years maize monoculture has increased dramatically due to increasing demand for maize according to the growth of the animal feed industry [27].



**Figure 1.** Study area.

## 2.2. Data Collection

The objective of this research is to study the areas dedicated to growing grain maize, seed maize and integrated farming. In this study, integrated farming refers to the cultivation of more than two different cash crops in the same area. Crops that were commonly grown in the Mae Chaem basin included peanut, potato, soybean, pumpkin, napa cabbage, strawberry, cabbage, shallot, Chinese parsley, avocado, coffee bean and other vegetables. The sampling method was purposive sampling, by which the researcher identified the expected numbers of farming villages and households that grew maize and maize seed and practiced integrated farming in relation to the objective of the study. To be

precise, this study aimed to collect data from farming households that grew grain maize and seed maize and practiced integrated farming, which meant that a sample size determined on the basis of the total number of households in the villages would be too large for this study. However, the number of samples to be taken from each village was determined based on the consultation with the sub-district administrative organization, making effective use of their broad knowledge of the area, expertise, and experience to come up with the group of samples that best represented the area. Onsite data collection included 10 sub-districts from two districts: (1) Mae Suek, Mae Na Chon, Tha Pha, Pang Hin Fon, Kong Khaek, Ban Thap, and Chang Khoeng sub-districts in Mae Chaem District; and (2) Chaem Luang, Ban Chan, and Mae Daet sub-districts in Galyani Vadhana District. Each of these sub-districts was represented by two of its villages, and each village was represented by approximately 10 of its households. In-depth interviews included 20 community leaders and 10 chief officials from district and sub-district administrative organizations. In total, there were 149 respondents.

Monthly temperature, relative humidity, rainfall and wind speed data were obtained from Chiang Mai meteorological station during the period 2012–2017. Data were analyzed to detect the climatological trend and connect with crop residual burning activities during the past 5 years.

### 2.3. Estimating Greenhouse Gas (GHG) Emissions

The volume of emissions of gas “*x*” from burning crop residues was estimated based on the amounts of crop residues burnt, called “activity data”, and the emission factor [28], as shown in Equation (1). In estimating activity data, the burned area, biomass density and burning efficiency were taken into account, as shown in Equation (2):

$$E_x = A \times EF_x \tag{1}$$

$$A = BA \times BD \times BE \tag{2}$$

where *x* is the emission type; *E<sub>x</sub>* (g) is the amount of emission of each type; *A* (kg) is the activity data; *EF<sub>x</sub>* (g kg<sup>-1</sup>) is the emission factor; *BA* (km<sup>2</sup>) is the burned area; *BD* (kg m<sup>-2</sup>) is the biomass per surface unit; and *BE* (dimensionless) is the burning efficiency.

In this study, the specific emission factors from several literature reviews were used, as shown in Table 1. In this study, *BD* is 0.40 kg m<sup>-2</sup> (range: 0.30–0.50 kg m<sup>-2</sup>) [29], while *BA* and *BE* were obtained from the field.

More specifically, chemical compositions of PM<sub>2.5</sub> emissions from maize burning were estimated using the emission factor from Li et al. [30].

**Table 1.** Summary of emission factors (EFs) specific to grain maize and maize seed open burning (Tier 2).

Name of Pollutant	Unit	EF (Open Burning)	Source
CO <sub>2</sub>	g kg <sup>-1</sup> dm	1515.00	Andrea and Merlet [31]
CO	g kg <sup>-1</sup> dm	38.80	Jenkins et al. [32]
CH <sub>4</sub>	g kg <sup>-1</sup> dm	2.70	Andrea and Merlet [31]
N <sub>2</sub> O	g kg <sup>-1</sup> dm	0.07	Andrea and Merlet [31]
NH <sub>3</sub>	g kg <sup>-1</sup> dm	2.40	Lee and Atkins [33]
NO <sub>x</sub>	g kg <sup>-1</sup> dm	1.80	Jenkins et al. [32]
Non-methane volatile organic compounds (NMVOCs)	g kg <sup>-1</sup> dm	4.50	Jenkins et al. [32]
SO <sub>x</sub>	g kg <sup>-1</sup> dm	0.20	Jenkins et al. [32]
Fine particulate matter (PM <sub>2.5</sub> )	g kg <sup>-1</sup> dm	6.00	Jenkins et al. [32]
PM <sub>10</sub>	g kg <sup>-1</sup> dm	6.20	Jenkins et al. [32]
Black carbon (BC)	mg kg <sup>-1</sup> dm	750.00	Turn et al. [34]

dm = Dry material.

## 2.4. Estimating Activity Data

### 2.4.1. Burned Area (BA)

The burned area was estimated based on the crop harvest area ( $HA$ ) and the ratio of the burned area to harvest area, as shown in Equation (3).

$$BA = HA \times \%BA \quad (3)$$

where  $HA$  is the area where the crop of each type was harvested and  $\%BA$  is the ratio of the burned area to harvest area. The data on harvest areas of both maize and maize seed in the study area were collected from Mae Chaem District Agriculture Office, and  $\%BA$  data were collected from the farmers.

### 2.4.2. Burning Efficiency (BE)

Burning efficiency was the actual ratio of both types of maize residues that were burned down. Burning efficiency was divided into four groups: (1) minimal burning (1–25%), (2) nearly half burned (26–50%), (3) more than a half burned (51–75%), and (4) nearly all burned (76–100%).

## 2.5. Ground Observation and Questionnaire Survey

Questionnaires were used to collect data about farm management practices, crop residue management, and burned areas. The main topics in the questionnaire included the following: (1) the cultivation area of crops; (2) the number of crop plantations; (3) the variety of crops grown; (4) planting, storing and harvesting methods; (5) the method of removing residues of crops from the farm after harvesting; (6) the reasons for burning or not burning residues; (7) did farmers burn their residues of both maize types? (If yes, how much and when?); (8) if the farmers did not burn the crop residues, what did they do with them? (9) How much of the residue was burned (1–25%, 26–50%, 51–75%, 76–100%)? (10) How much of the planting area was burned (1–25%, 26–50%, 51–75%, 76–100%)? (11) What were the income, cost, and revenue per crop (baht/year)? (12) Was there any other income, aside from maize (baht/year)? (13) Was there any policy or support from the government and/or any related agency concerning maize production? (14) Was there any policy or support from the government and/or any related agency concerning aspects other than maize production? (15) If they were asked to stop growing maize and start growing other crops, would they be willing to? Why? What were the advantages and disadvantages?

## 3. Results

### 3.1. Meteorological Data

The meteorological data collected at Chiang Mai Province during the period of 2012–2017 is shown in Figure 2. The average temperatures of the 5-year period ranged from 29.8 °C (January) to 37.4 °C (April). The monthly average rainfall ranged from 9.8 mm (March) to 200.2 mm (August). The average relative humidity and wind speed ranged from 54.0% (March) to 79.2% (September), and 1.5 km h<sup>-1</sup> (January) to 2.9 km h<sup>-1</sup> (May), respectively.

### 3.2. Burning Seasons of Grain Maize, Seed Maize and Integrated Farming

Field data showed that, among the farmers in the Mae Chaem basin, 29% and 27% burned residues of grain maize and seed maize in April and May, respectively. After that, the most common months for burning these residues were December (21%), February (7.7%), November (5.8%), January (3.8%), and June, July, and October (1.9% each). However, none of them burned the maize residue in March, August and September. Meanwhile, 31.82% burned crop residues from the integrated farming system in April, 22.72% in May, 9.09% in January, March, and December, and 4.54% in February, August,

September, and November. Also, it was found that none of the farmers burned the crop residue from the integrated farming system in June, July or October (Figure 3).

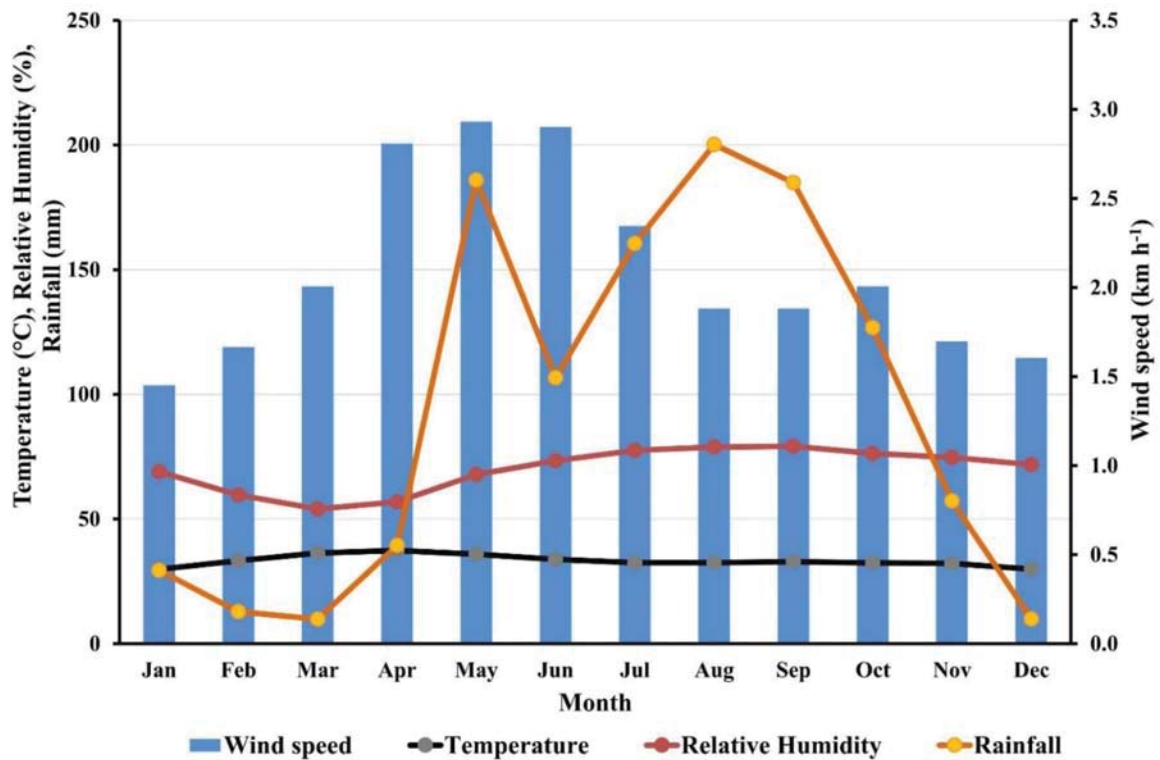


Figure 2. Temperature, relative humidity, rainfall and wind speed at Chiang Mai Province during the period 2012–2017.

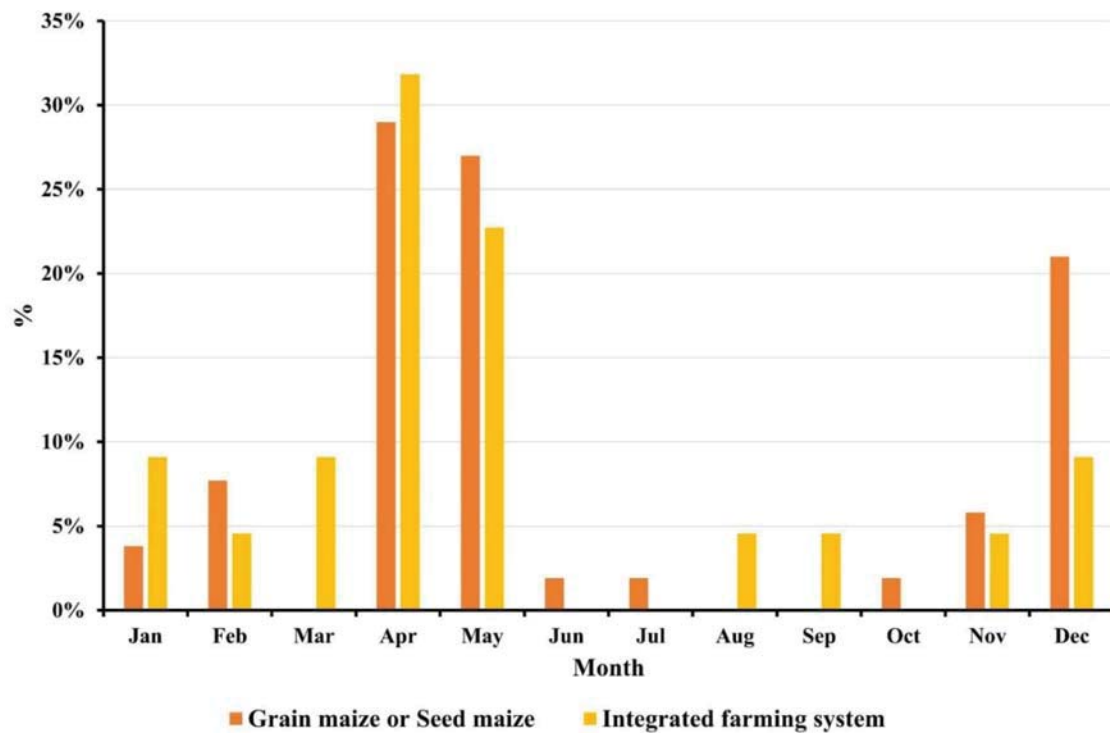


Figure 3. Burning seasons of grain maize, seed maize and integrated farming system.

### 3.3. Method of Removing Residues from the Field

Approximately 50% of the farmers left the grain maize and seed maize residues in their fields without burning or removing them while 41% of them burned them in the field. In addition, it was found that 4% of the farmers took the residue out of their fields to use it for other purposes, and 5% of them practiced all three methods: burning, removing and leaving in place. Most of the farmers (approximately 62%) left the crop residue from the integrated farming system within their fields, while 24% of them burned it down. Only 11% of them removed the crop residue from their fields to use it for other purposes and 3% of them practiced all three methods (Figure 4).

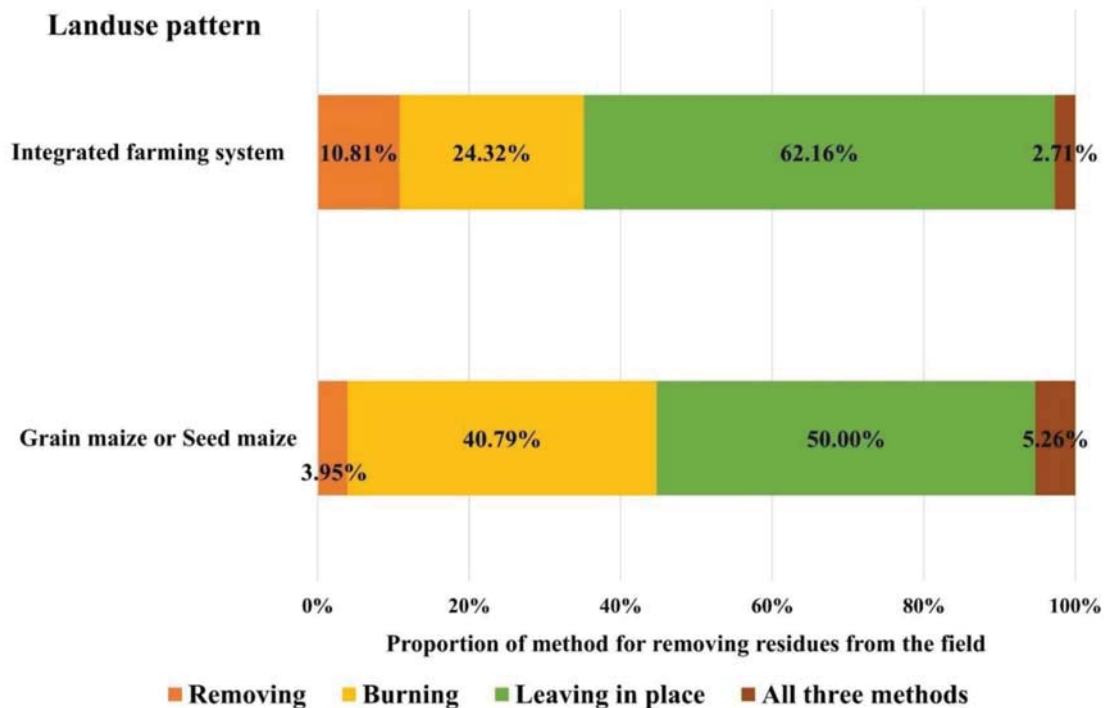
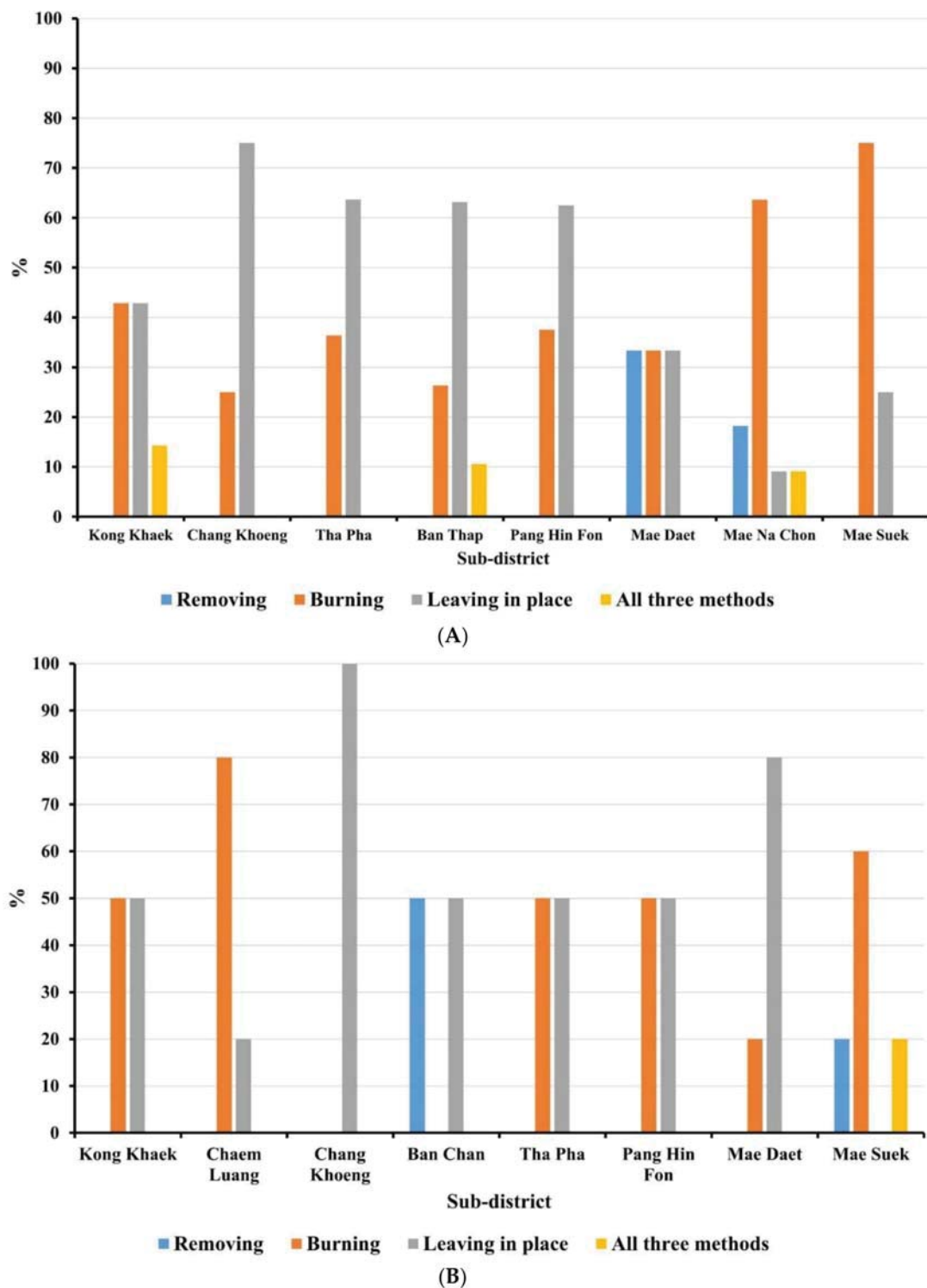


Figure 4. Method of removing residues from the field.

However, farmers in each area had different ways of dealing with the crop residues. The results showed that 75% of farmers in Chang Khoeng sub-district left the grain maize and seed maize residue on their fields, while 25% of them burned it. Of the farmers in Mae Daet sub-district, 33.33% removed the residue from their fields, 33.33% burned it down, and the remaining 33.34% left it within their fields. Moreover, of the farmers in Mae Suek sub-district, 75% burned the residue on their fields while 25% of them left it on their fields (Figure 5A). Figure 5B illustrates how crop residues were dealt with by farmers who practiced integrated farming. It was found that in Chaem Luang sub-district most of the farmers burned it down in their fields (80%) and 20% of them left it in their fields. Farmers in Ban Thap and Pang Hin Fon sub-districts were similar: 50% of them burned the crop residue in their fields and the other 50% left it in their fields. Meanwhile, Mae Suek sub-district was the only area where farmers did not leave any crop residue in their fields, with 60% of them burning it down and 20% of them removing it from their fields. It was also found that in Chang Khoeng sub-district, all the farmers left the crop residue in their fields.

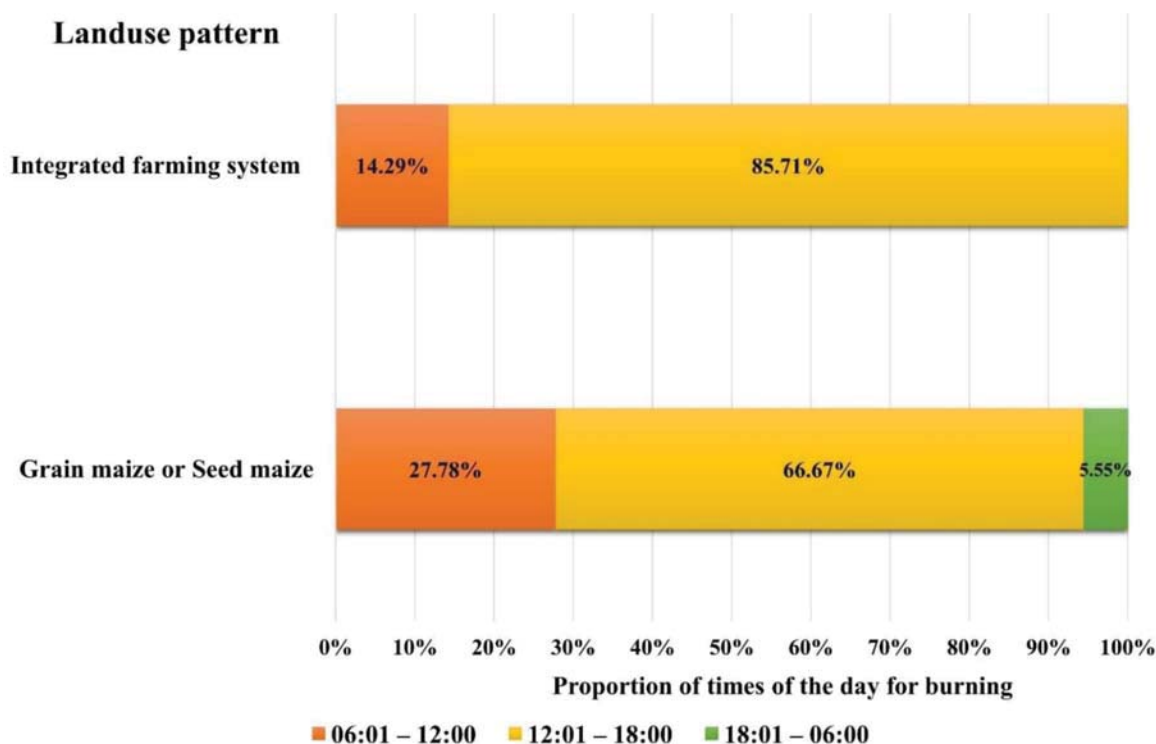


**Figure 5.** Method of removing residues from the field of each sub-district: (A) grain maize and seed maize, (B) integrated farming system.

### 3.4. Times of the Day at Which Crop Residues Were Burnt

Most of the farmers (66.67%) burned the grain maize and seed maize residues in the afternoon (12:01–18:00 h), while 27.78% of them did so in the morning (06:01–12:00 h), and 5.55% of them did so in the evening (18:01–06:00 h). Moreover, the results showed that 85.71% of the farmers burned the

crop residue from the integrated farming system in the afternoon (12:01–18:00 h), 14.29% did so in the morning (06:01–12:00 h), and none of them did so in the evening (18:01–06:00 h) (Figure 6).

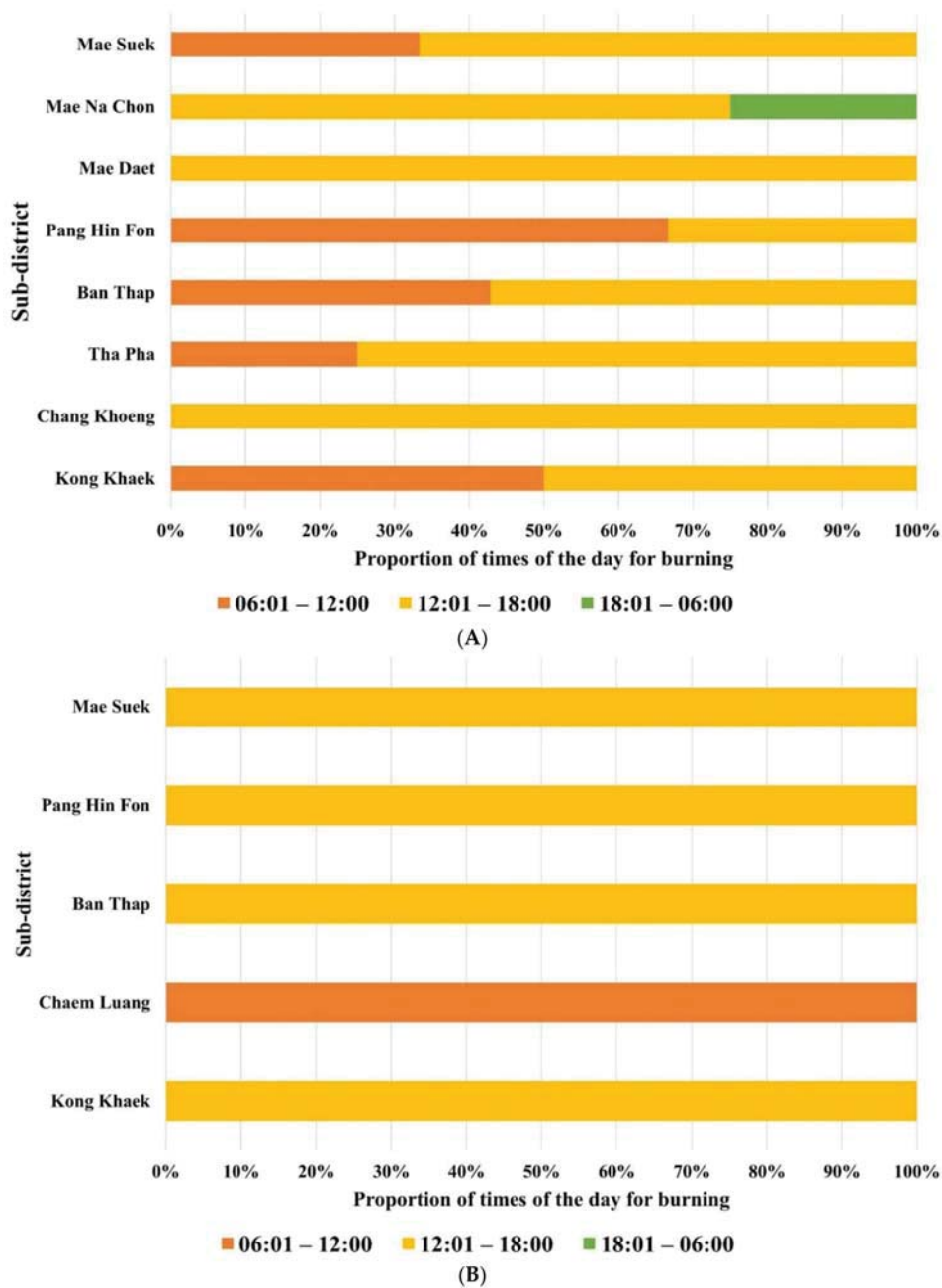


**Figure 6.** Times of the day for burning crop residues.

Concerning each area, all of the farmers in Chang Khoeng and Mae Daet sub-districts burned the grain maize and seed maize residues in the afternoon. Of the farmers in Mae Na Chon sub-district, 75% burned it in the afternoon and 25% of them did so in the evening. On the other hand, 67% of the farmers in Pang Hin Fon sub-district burned it in the morning and 33% of them did so in the afternoon (Figure 7A). In the case of integrated farming, most of the farmers in Kong Khaek, Ban Thap, Pang Hin Fon, Mae Suek, and Mae Daet sub-districts chose to burn the crop residue in the afternoon. Meanwhile, most of the farmers (86%) in Chaem Luang sub-districts chose to burn the crop residue in the morning (Figure 7B). In addition, it was found that 61% of the burning activity took between one to two hours, while 39% of the activity took less than one hour.

### 3.5. GHG Emissions from Burning Grain Maize and Seed Maize Residues

From highest to lowest amounts, the GHG emissions that resulted from burning grain maize and seed maize residues were as follows:  $\text{CO}_2 > \text{CO} > \text{PM}_{10} > \text{PM}_{2.5} > \text{NMVOCs} > \text{CH}_4 > \text{NO}_x > \text{BC} > \text{SO}_x > \text{N}_2\text{O}$ . Estimated amounts of  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ , NMVOCs,  $\text{CH}_4$ ,  $\text{NO}_x$ , BC,  $\text{SO}_x$ , and  $\text{N}_2\text{O}$  emissions from burning grain maize residues were 9879.3, 253.0, 40.4, 39.1, 29.3, 17.6, 11.7, 4.9, 1.3, and 0.5  $\text{kg ha}^{-1} \text{ year}^{-1}$ , respectively (Table 2). Meanwhile, the estimated amounts of the greenhouse gases  $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ , NMVOCs,  $\text{CH}_4$ ,  $\text{NO}_x$ , BC,  $\text{SO}_x$ , and  $\text{N}_2\text{O}$  emitted by burning seed maize residues were 16,851.7, 656.1, 104.8, 101.5, 76.1, 45.7, 30.4, 12.7, 3.4, and 1.2  $\text{kg ha}^{-1} \text{ year}^{-1}$ , respectively (Table 3). Overall, the total amount of GHG emissions caused by the burning of seed maize residues was 23.94% higher than the total emissions caused by the burning of grain maize residues.



**Figure 7.** Times of the day for burning crop residues of each sub-district: (A) grain maize and seed maize, (B) integrated farming system.

### 3.6. GHG Emissions from Burning Crop Residues under the Integrated Farming System

Similarly, GHG emissions that resulted from burning crop residues from the integrated farming system were as follows:  $\text{CO}_2 > \text{CO} > \text{PM}_{10} > \text{PM}_{2.5} > \text{NMVOCs} > \text{CH}_4 > \text{NO}_x > \text{BC} > \text{SO}_x > \text{N}_2\text{O}$ . On average, the estimated amounts of the greenhouse gases emitted from burning crop residues under the integrated farming system were 6383.4, 163.5, 26.1, 25.3, 19.0, 11.4, 7.6, 3.2, 0.8, and 0.3  $\text{kg ha}^{-1} \text{ year}^{-1}$  (Table 4). In addition, it was found that the farmers in Ban Thap sub-district who grew grain maize and, after harvesting, shallot, accounted for the greatest amount of GHG emissions from burning crop residues among all crops grown in the area, whereas the farmers in Chaem Luang sub-district who grew Japanese pumpkin twice a year accounted for the smallest amount of GHG emissions.

**Table 2.** Air-pollutant emissions from burning grain maize residues.

Sub-District	Land-use Pattern and Varieties	CO <sub>2</sub>	CO	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOCs	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	BC
		kg ha <sup>-1</sup> year <sup>-1</sup>									
Kong Khaek	shallots, glutinous rice, grain maize, seed maize	3607.1	92.4	6.4	0.2	4.3	10.7	0.5	14.3	14.8	1.8
Tha Pha	pumpkin, grain maize	5908.5	151.3	10.5	0.3	7.0	17.6	0.8	23.4	24.2	2.9
Ban Thap	grain maize	5681.3	145.5	10.1	0.3	6.8	16.9	0.8	22.5	23.3	2.8
Mae Daet	shallots, upland rice, grain maize	12,120.0	310.4	21.6	0.6	14.4	36.0	1.6	48.0	49.6	6.0
Mae Na Chon	grain maize	22,725.0	582.0	40.5	1.1	27.0	67.5	3.0	90.0	93.0	11.3
Mae Suek	grain maize	6775.3	173.5	12.1	0.3	8.1	20.1	0.9	26.8	27.8	3.4
	grain maize	12,338.1	316.0	22.0	0.6	14.7	36.6	1.6	48.9	50.5	6.1
<b>Average</b>		<b>9879.3</b>	<b>253.0</b>	<b>17.6</b>	<b>0.5</b>	<b>11.7</b>	<b>29.3</b>	<b>1.3</b>	<b>39.1</b>	<b>40.4</b>	<b>4.9</b>

**Table 3.** Air-pollutant emissions from burning seed maize residues.

Sub-District	Land-use Pattern and Varieties	CO <sub>2</sub>	CO	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOCs	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	BC
		kg ha <sup>-1</sup> year <sup>-1</sup>									
Kong Khaek	shallots, pumpkin, seed maize	9561.6	244.9	17.1	0.4	11.4	28.4	1.3	37.9	39.1	4.8
Chang Khoeng	shallots, seed maize	12,271.5	314.3	21.9	0.6	14.6	36.4	1.6	48.6	50.3	6.1
Tha Pha	seed maize	18,066.4	462.7	32.2	0.8	21.5	53.7	2.4	71.6	73.9	8.9
Ban Thap	seed maize	21,829.3	559.1	38.9	1.0	25.9	64.8	2.9	86.4	89.3	10.8
Pang Hin Fon	seed maize	20,009.4	2083.8	145.0	3.8	96.7	241.7	10.8	322.3	333.0	40.3
Mae Na Chon	seed maize	18,455.8	472.7	32.9	0.8	21.9	54.8	2.4	73.1	75.6	9.1
Mae Suek	seed maize	17,768.1	455.1	31.7	0.9	21.1	52.8	2.3	70.4	72.7	8.8
<b>Average</b>		<b>16,851.7</b>	<b>656.1</b>	<b>45.7</b>	<b>1.2</b>	<b>30.4</b>	<b>76.1</b>	<b>3.4</b>	<b>101.5</b>	<b>104.8</b>	<b>12.7</b>

**Table 4.** Air-pollutant emissions from burning crop residues under integrated farming system.

Sub-District	Land-use Pattern and Varieties	kg ha <sup>-1</sup> year <sup>-1</sup>										
		CO <sub>2</sub>	CO	CH <sub>4</sub>	N <sub>2</sub> O	NO <sub>x</sub>	NMVOCs	SO <sub>x</sub>	PM <sub>2.5</sub>	PM <sub>10</sub>	BC	
Kong Khaek	888 grain maize	1212.0	31.0	2.2	0.1	1.4	3.6	0.12	4.8	5.0	0.6	
	888 grain maize, shallots	-	-	-	-	-	-	-	-	-	-	
Chaem Luang	peanuts, red beans	6817.5	174.6	12.1	0.3	8.1	20.3	0.9	27.0	27.9	3.4	
	Japanese pumpkin, peanuts	5113.1	130.9	9.1	0.3	6.1	15.2	0.7	20.3	20.9	2.6	
	Japanese pumpkin, Japanese pumpkin	378.8	9.7	0.7	0.0	0.4	1.1	0.1	1.5	1.6	0.2	
	Japanese pumpkin, red beans	5681.3	145.5	10.1	0.3	6.8	16.9	0.8	22.5	23.3	2.8	
	peanuts, peanuts	511.3	13.1	0.9	0.0	0.6	1.5	0.1	2.0	2.1	0.3	
	red beans, avocado, pumpkin	-	-	-	-	-	-	-	-	-	-	
	rice, red bean, avocado, coffee bean	-	-	-	-	-	-	-	-	-	-	
Chang Khoeng	lettuce, potato, bog choy, parsley	-	-	-	-	-	-	-	-	-	-	
	strawberry 329, strawberry 80	-	-	-	-	-	-	-	-	-		
Ban Chan	pumpkin, pumpkin	-	-	-	-	-	-	-	-	-	-	
	Japanese pumpkin, peanuts	-	-	-	-	-	-	-	-	-	-	
Ban Chan	corn, peanuts	-	-	-	-	-	-	-	-	-	-	
	pear, avocado, plum, cape gooseberry	-	-	-	-	-	-	-	-	-	-	
	kale, coriander, rice, Japanese pumpkin	-	-	-	-	-	-	-	-	-	-	
	cabbage, lettuce, rice, Japanese pumpkin	-	-	-	-	-	-	-	-	-	-	
	Japanese pumpkin, vegetable salad, cabbage, coriander, vocado, passion fruit, pear	-	-	-	-	-	-	-	-	-	-	
Ban Thap	Nakhon Sawan 3 grain maize, red beans	3933.2	100.8	7.0	0.2	4.7	11.7	0.5	15.6	16.1	1.9	
	888 grain maize, shallots	26,512.5	679.0	47.3	1.3	31.5	78.8	3.5	105.0	108.5	13.1	
Mae Daet	strawberry 329, strawberry 80	-	-	-	-	-	-	-	-	-	-	
	strawberry 80, strawberry 329, cabbage	-	-	-	-	-	-	-	-	-	-	
Mae Suek	strawberry 80, strawberry 329, napa cabbage	-	-	-	-	-	-	-	-	-	-	
	strawberry 80, strawberry 329	-	-	-	-	-	-	-	-	-	-	
	NK328 grain maize, NK62 grain maize, Japanese pumpkin	-	-	-	-	-	-	-	-	-	-	
Mae Suek	potatoes, avocado, grape, cabbage	-	-	-	-	-	-	-	-	-	-	
	green grapes, seed maize	-	-	-	-	-	-	-	-	-	-	
	cabbage, potatoes, avocado, grapes	-	-	-	-	-	-	-	-	-	-	
Average	NK grain maize, pioneer grain maize, 888 grain maize, napa cabbage, arabica coffee	927.6	23.8	1.6	0.1	1.1	2.8	0.1	3.7	3.8	0.4	
		6383.4	163.5	11.4	0.3	7.6	19.0	0.8	25.3	26.1	3.2	

### 3.7. Chemical Components Characteristics in PM<sub>2.5</sub>

The estimation shows that the integrated farming system produced the lowest amount of chemical composition of PM<sub>2.5</sub> emissions, followed by grain maize and seed maize, respectively. OC was detected as the dominant chemical composition in PM<sub>2.5</sub> mass, followed Cl<sup>-</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, EC, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>, respectively. The top 10 pollution levels of heavy metals in the PM<sub>2.5</sub> mass were in the following order: Pb > K > Ti > Mn > V > Sr > S > Cd > As > Se in all three land-use patterns (Table 5).

**Table 5.** Chemical composition of PM<sub>2.5</sub> emissions from agricultural residue burning.

Chemical Species	Grain Maize (g ha <sup>-1</sup> year <sup>-1</sup> )	Seed Maize (g ha <sup>-1</sup> year <sup>-1</sup> )	Integrated Farming System (g ha <sup>-1</sup> year <sup>-1</sup> )
OC	152.59	395.61	98.48
EC	13.69	35.50	8.84
Cl <sup>-</sup>	105.64	273.88	68.18
NO <sub>3</sub> <sup>-</sup>	2.74	7.10	1.77
SO <sub>4</sub> <sup>2-</sup>	8.61	22.32	5.56
NH <sub>4</sub> <sup>+</sup>	46.95	121.73	30.30
K <sup>+</sup>	39.13	101.44	25.25
Al	0.00016	0.00043	0.00011
Ca	0.00027	0.00070	0.00017
Fe	0.00005	0.00014	0.00004
Si	0.00021	0.00055	0.00014
Mg	0.00021	0.00055	0.00014
K	0.03169	0.08216	0.02045
Na	0.00078	0.00203	0.00051
S	0.00309	0.00801	0.00199
Sc	0.00027	0.00071	0.00018
Ti	0.00548	0.01420	0.00354
V	0.00391	0.01014	0.00253
Mn	0.00509	0.01319	0.00328
Co	0.00016	0.00041	0.00010
Ni	0.00133	0.00345	0.00086
Zn	0.00110	0.00284	0.00071
Ga	0.00012	0.00030	0.00008
As	0.00270	0.00700	0.00174
Se	0.00231	0.00598	0.00149
Sr	0.00333	0.00862	0.00215
Zr	0.00157	0.00406	0.00101
Mo	0.00027	0.00071	0.00018
Ag	0.00070	0.00183	0.00045
Cd	0.00274	0.00710	0.00177
Sb	0.00020	0.00051	0.00013
Ba	0.00102	0.00264	0.00066
Tl	0.00035	0.00091	0.00023
Pb	0.04304	0.11158	0.02778

## 4. Discussions

### 4.1. Prescribed Agricultural Burning Behaviors

Prescribed burning can be accomplished by applying knowledge of and skill with burning to specific site and weather conditions [35]. However, common prescribed burning parameters influencing land-management purposes are rainfall, relative humidity, temperature and wind speed [36,37]. Based on our findings, the majority of farmers in the Mae Chaem basin burned residues of grain maize and seed maize during April and May (Figure 3) and mostly in the afternoon (Figure 6). These burning behaviors are in line with the supportive weather conditions for burning. This is because the high values of temperature and wind speed, and less rainfall and relative humidity

during the burning period (Figure 2), result in maize residues that are burned easily and quickly. This finding can be supported by Indiana Department of Natural Resources [35], which indicated that high temperatures help dry residues quickly and increase the heat intensity of the fire. High wind speed can also increase the spread of flames and airborne particulate distribution, while calm wind supports air-pollutant accumulation. Moreover, temperature and wind speed generally increase to a maximum in the early afternoon and then decrease to a minimum after sunset.

Furthermore, fires are more intense under low rainfall or in an area to be burned that has dried after rainfall. These results are due to the rainfall effects on relative humidity of the surrounding air and moisture content of residues; if they retain more moisture, they are less apt to burn. Our results are also consistent with Chantara et al. [38] who found that the concentrations of atmospheric pollutants in Chiang Mai (Thailand) were high from January to April (dry season), decreased from May to October (wet season), and increased again from November to December (the cool, dry season). The Pollution Control Department (PCD) [39] also reported that open biomass burning in agricultural and forest areas in northern Thailand produced vast smoke/haze during the dry season (February–April), which is consistent with Chantara et al. [38] and Sillapapiromsuk et al. [40].

#### 4.2. Field Burning of Crop Residues and GHG Emissions

Maize cultivation in the Mae Chaem basin takes place in the non-irrigated highlands. After harvesting, farmers leave the maize residues in the field until the next crop. However, open field burning of crop residues is a simple method by which farmers in this area can clean the agricultural land to facilitate soil tillage. Several studies have confirmed that open burning of crop residues is an efficient way to control insects, diseases and the emergence of invasive weed species [41,42]. On the other hand, it has been argued that this practice has negative impacts in terms of national economic losses [43,44], environmental degradation [45,46], health impacts [47], and soil organic matter (SOM) loss [48], which leads to a reduction of soil fertility and crop production.

Importantly, open field burning of crop residue transforms soil nutrients to gaseous form which is released to the atmosphere [49]. It has been reported that field burning of crop residues represents a major source of GHGs and aerosols [50,51]. These trace gases have negative impacts not only on the environment but also on human and animal health, especially in pregnant woman and small children [52,53]. According to Singh et al. [54], the medical records of the civil hospital of Jira, Punjab, indicated that there was a 10% increase in the number of patients within 20–25 days of the burning period. This is because more than 60% of the people live in the rice cultivation areas and rice residues are burned every season. In addition, Gadde et al. [55], Gullett and Touati [56], and Lin et al. [57] mentioned that burning crop residues results in the release of harmful chemicals to the atmosphere such as polychlorinated dibenzo-p-dioxins, polycyclic aromatic hydrocarbons, and polychlorinated dibenzofurans, which are referred to as dioxins. These air pollutants have toxicological properties and are potential carcinogens. Air pollution can result in the death of animals, as the high levels of CO<sub>2</sub> and CO in the animals' blood can convert the normal hemoglobin into deadly hemoglobin. There can also be a potential decrease in the yield of the milk-producing animals [53].

Moreover, the burning of crop residues affects not only soil fertility but also farmers' income, because the conversion of forest areas to agricultural land has resulted in a significant decline in SOM content [58]. On steep slopes in the highlands, this can easily result in soil erosion and a decline of soil fertility. According to Boonlertnirun and Jompuk [59], nitrogen and sulfur most frequently limit the maize yield and are emitted to the atmosphere in fires. Heard and Hay [60] found that about 98–100% of the nitrogen, 24% of the phosphorus, 35% of the potassium, and 75% of the sulfur were lost through burning in Manitoba, Western Canada. Moreover, Gupta et al. [61] estimated that the burning of straw increases soil temperature up to 33.8–42.2 °C (1-cm depth). However, for maize production in the highlands, an alternative to residue burning is needed, and this takes the form of the sequestration of carbon from plant biomass into SOM. To enhance the nutrient balance of maize-planting areas, implementing crop rotation (e.g., mung bean, soybean, red bean, pumpkin) under different types of

fertilizers and incorporating these crop residues in the soil can help to develop effective policies to address nutrient-related environmental problems and achieve a sustainable maize stover harvest [62].

#### 4.3. Chemical Compositions of $PM_{2.5}$ Emissions from Agricultural Burning

In terms of air-quality assessment, an important parameter is PM, especially  $PM_{2.5}$  that causes the negative effects on human health (such as impeded breathing, chronic asthma and lung cancer), visibility, radiation [63–66] and climate change [67]. Our finding revealed that OC was the dominant chemical composition in  $PM_{2.5}$  mass, which is in line with Turn et al. [34] who reported that about 50% of PM emission from crop residue combustion is carbonaceous aerosol. Moreover, our findings are in line with several studies, which reported that  $Cl^-$ ,  $NH_4^+$ ,  $K^+$ , EC,  $SO_4^{2-}$  and  $NO_3^-$  were derived from the combustion process, while  $K^+$  and  $Cl^-$  were the dominant pollution from agricultural residue burning [40,68–71]. Long et al. [72] reported a 34% increase in ambient  $PM_{2.5}$  concentrations from agricultural burning in the North China Plain. Cheng et al. [73] attributed 37% of  $PM_{2.5}$  mass, 70% of OC, and 61% EC to crop burning in southern China. Elevated  $K^+$  and  $Cl^-$  abundances in PM have been reported for biomass burning in China [74] and in Korea [75]. In Thailand, Chantara et al. [38] determined the seasonal variation of atmospheric ion species and gases in the suburban area of Chiang Mai Province. Their results show that the first component had a high loading of  $SO_4^{2-}$ ,  $NH_4^+$  and  $K^+$ , which was probably generated from fuel combustion, agricultural activity and biomass burning, respectively. In addition, Khamkaew et al. [19], Vinitketkumnuen et al. [76] and Chantara et al. [77] found the major elements in the  $PM_{2.5}$  from biomass burning in Chiang Mai Province were  $K^+$ , Mg, Al and Fe.

Moreover,  $PM_{2.5}$  contain various toxic heavy metal elements, among which Pb represented the highest concentration of heavy metals in  $PM_{2.5}$  from agricultural burning compared with the other elements in this area. Previous studies have demonstrated that Pb is a carcinogenic heavy metal that can be enriched in the human body via inhalation, dermal absorption and ingestion [78–80]. It should be noted that an integrated farming system generated the lowest concentrations of heavy metals in  $PM_{2.5}$  due to the lower amount of maize residue burning than other land-use patterns.

#### 4.4. Comparisons of GHG Emissions among Grain Maize, Seed Maize and Integrated Farming

Comparisons of GHG emissions among the three land-use patterns—grain maize, seed maize, and integrated farming—pointed to the fact that farmers who grew seed maize were responsible for the largest amount of GHG emissions, followed by those who grew grain maize and those who practiced integrated farming, respectively. It was also found that most of the farmers who did not grow grain maize or seed maize but grew other plants such as strawberry, Japanese pumpkin and cabbage did not burn any crop residues. In addition, field data showed that there were several reasons why the farmers burnt their crop residues. First, residues of grain maize and seed maize are hardly degradable and lead to pests and weeds. Secondly, the residues are a hindrance to farming activities such as tillage, pesticide, herbicide and fertilizer applications, and planting. Thirdly, burning is a cost- and time-saving method. Fourthly, it is difficult to remove grain maize and seed maize residues from the fields as trucks cannot get into them. Finally, some farmers understand that burning is allowed before or after the period announced by the government.

#### 4.5. Proposed Policies

Proactive and reactive measures should be taken in a well-organized and systematic fashion and should engage all related parties. The following plausible solutions for particulate pollution and forest-fire control are suggested: (1) Urgent measures: state agencies must enhance their collaboration and work to officially announce severe particulate pollution warnings in specific areas to urge the government to allocate budgets to help alleviate hardship among those affected. A royal rainmaking station should be established in the northern part of Thailand to cope with the particulate pollution issue. In addition, there should be communication with countries in the Greater Mekong Subregion

(GMS)—including Myanmar, Vietnam, and Laos—in order to improve how these countries prevent and cope with open biomass burning. (2) Long-term measures: the concept of “wet forest” that was initiated by King Bhumibol Adulyadej, or King Rama IX, should be incorporated into the proactive and reactive measures for particulate pollution and forest fire using the following methods: first, water from the waterways should be used and various plants should be planted along the waterways. Second, a forest fire prevention system should be built with a wet fire line using irrigation water and rain water. Third, fast-growing trees should be grown to cover a water channel to gradually increase the surrounding moisture and spread it to both sides of the channel, thus helping plants to grow and preventing forest fires, since fires normally thrive on drier land. Fourth, a check dam should be built to close off a water channel or small streams at various intervals to retain some of the water and sediment. The retained water will be absorbed into the soil and will increase moisture on both banks, thus making it a wet forest. Fifth, water should be pumped to the highest possible location and released in small amounts so that it is absorbed into the soil to grow “mountain forests” as wet forests. Sixth, two meters’ worth of banana plants should be planted in forests as they can retain water better than other plants can, which will reduce water loss.

More importantly, policy makers urgently need to include PM<sub>2.5</sub> concentrations in Thailand’s air quality index (PM<sub>2.5</sub> AQI) in order to provide the public with more comprehensive air-quality data, and implement the measures to control and reduce air pollution in the future.

## 5. Conclusions

The majority of farmers in the Mae Chaem basin burned residues of grain maize and seed maize during April and May and mostly in afternoon. These burning behaviors are in line with the supportive weather conditions for burning that reflect high values of temperature and wind speed, and less rainfall and relative humidity result in maize residues that are burned easily and quickly. The amount of GHG emissions from burning crop residues showed that grain maize planting generated emissions of CO<sub>2</sub> > CO > PM<sub>10</sub> > PM<sub>2.5</sub> > NMVOCs > CH<sub>4</sub> > NO<sub>x</sub> > black carbon > SO<sub>x</sub> > N<sub>2</sub>O with average values of 9879.3, 253.0, 40.4, 39.1, 29.3, 17.6, 11.7, 4.9, 1.3, and 0.5 kg ha<sup>-1</sup> year<sup>-1</sup>, respectively; while seed maize planting demonstrated about 23.94% higher emissions than maize planting, with values of 16,851.7, 656.1, 104.8, 101.5, 76.1, 45.7, 30.4, 12.7, 3.4, and 1.2 kg ha<sup>-1</sup> year<sup>-1</sup>, respectively. Meanwhile, the integrated farming system generated GHG emissions, with average values of 6383.4, 163.5, 26.1, 25.3, 19.0, 11.4, 7.6, 3.2, 0.8, and 0.3 kg ha<sup>-1</sup> year<sup>-1</sup>, respectively.

The integrated farming system recorded the lowest amount of chemical composition of PM<sub>2.5</sub> emissions, followed by grain maize and seed maize, respectively. OC was detected as the dominant chemical composition in PM<sub>2.5</sub> mass, followed by Cl<sup>-</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, EC, SO<sub>4</sub><sup>2-</sup>, and NO<sub>3</sub><sup>-</sup>, respectively. The top 10 pollution levels of heavy metals in the PM<sub>2.5</sub> mass were in the following order: Pb > K > Ti > Mn > V > Sr > S > Cd > As > Se.

This study strongly supports the implementation of the integrated farming system in Mae Chaem basin. More importantly, including PM<sub>2.5</sub> concentrations to upgrade Thailand’s air-quality index (PM<sub>2.5</sub> AQI) is an urgent need for policy makers.

**Acknowledgments:** This article was a part of the research grant nr. RDG6020014. Furthermore, the authors would like to thank the reviewers for their helpful comments to improve the manuscript.

**Author Contributions:** Noppol Arunrat collected and preformed data analysis, wrote and revised the manuscript. Nathsuda Pumijumngong collected and preformed data analysis, and provided advice. Sukanya Sereenonchai collaborated in discussing the manuscript and provided advice to this study.

**Conflicts of Interest:** The authors declare no conflict of interest.

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## Assessment of Landuse Change and Climate Change on Runoff in Mae Chaem Watershed

### การประเมินผลกระทบจากการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินภายใต้การเปลี่ยนแปลงสภาพ

### ภูมิอากาศต่อปริมาณน้ำท่า ในลุ่มน้ำแม่แจ่ม

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#### ABSTRACT

The purpose of this study is to study the effect on runoff from the change of landuse under A2 and B2 climate scenario in Mae Chaem watershed by using SWAT model. To run SWAT various input data are required, Digital Elevation Model: DEM, climatology data, soil data, and landuse/land cover. The reliability of a simulated value shall be compared with an observed value via Coefficient of determination ( $R^2$ ) and Nash-sutcliffe efficiency ( $E_{ns}$ ). This study is divided into 3 cases which are a. Present landuse, b. A huge agriculture expansion and c. Reforestation. The result shows that among these 3 cases the most area cover with agriculture area provides the most runoff in Mae Chaem watershed.

#### บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อประเมินปริมาณน้ำท่าต่อการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินภายใต้การเปลี่ยนแปลงสภาพภูมิอากาศแบบ A2 และ B2 ต่อปริมาณน้ำท่าบริเวณลุ่มน้ำแม่แจ่ม โดยการใช้แบบจำลอง SWAT model ซึ่งเป็นแบบจำลองนี้จะประมวลผลปริมาณน้ำท่าจากข้อมูลนำเข้าได้แก่ แบบจำลองระดับสูงเชิงเลข (Digital Elevation Model : DEM) ข้อมูลอุตุนิคมวิทยา ข้อมูลปฐพีวิทยา และข้อมูลการใช้ประโยชน์ที่ดิน บริเวณลุ่มน้ำแม่แจ่ม ทำการวิเคราะห์ผลของความน่าเชื่อถือของแบบจำลองโดยเปรียบเทียบผลของปริมาณน้ำท่าที่ได้จากการจำลองและปริมาณน้ำท่าที่ได้จากการตรวจวัดจริงจากวิธีการ ซึ่งการศึกษาจะถูกแบ่งออกเป็น 3 กรณี ได้แก่ กรณีที่ไม่มีการเปลี่ยนแปลงการใช้ประโยชน์ที่ดิน กรณีที่การใช้ประโยชน์ที่ดินที่เป็นพื้นที่การเกษตรกรรมทั้งหมดถูกเปลี่ยนเป็นพื้นที่ป่า และกรณีที่การใช้ประโยชน์ที่ดินที่เป็นพื้นที่ป่าทั้งหมดถูกเปลี่ยนเป็นพื้นที่เกษตรกรรม จากผลการศึกษาพบว่า การเปลี่ยนแปลงการใช้ประโยชน์ที่ดินจากพื้นที่ป่ามาเป็นพื้นที่เกษตรกรรมส่งผลให้ปริมาณน้ำไหลบ่าหน้าดินบริเวณลุ่มน้ำแม่แจ่มเพิ่มขึ้น

**Keywords:** Runoff, SWAT

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## Introduction

Thailand is an agricultural - based country. Since the habits of Thai's farmers have changed due to the highly competition in the present, from a Simultaneous Cropping System to a Single Crop Yields (The Organic Agriculture Development Center, 2010). An expansion of hill agriculture has led to more and more deforestation. This impact shall lead to erosion that can cause sedimentation in low land river. A high sedimentation in a particular spot shall lead to a shallow and direction changes. Hence, either drought or flood may occur.

To prevent the above threat, a good stimulation is required in order to understand the consequences from hill agriculture in each scenario. Runoff, nutrient, and sediment are keys component of these impact. Considering the agriculture activities, there are other factors that can drift the natural behavior of water such as climate changes, land use, specific management, and etc. which lead to various situations and managerial ways.

The Soil and Water Assessment Tool SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds SWAT model has been used to simulate from a small watershed to a huge watershed scale in both quality and quantity of surface water and groundwater and also simulate the impact from landuse change, and climate change (SWAT, 2017).

## Objectives of the study

The aim of this study is to assessing the amount of runoff in Mae Chaem watershed in accordance with landuse change scenarios under A2 and B2 climate scenario.

## Material and Methodology

### Data preparation

To simulate runoff, SWAT model required a data to process. The input data collect in this study are Base map and Climatology data. The data were requested from Land Development Department and Northern Meteorological Center Meteorological Department as listed in table 1

**Table 1** Input data for SWAT model

Type of data	Details	Source of data	Step
<b>Base map</b>			
• Dem 30	- A projected Grid shows the elevation in Mae Chaem.	- Land Development Department	- Project setup
• Mae Chaem Boundary	- A projected Grid shows the boundary of Mae Chaem.	- Land Development Department	- Water delination
• River line	- A projected Grid shows the river line in Mae Chaem.	- Land Development Department	- Water delination
• Land use	- A projected Grid shows the	- Land Development Department	- HRU analysis

**Table 1** Input data for SWAT model (Cont.)

Type of data	Details	Source of data	Step
<ul style="list-style-type: none"> <li>Soil type</li> </ul>	- A projected Grid shows the soil characteristics in Mae Chaem.	- Land Development Department	- HRU analysis
<b><u>Weather data</u></b>			
<ul style="list-style-type: none"> <li>Temperature</li> </ul>	- The temperature collected from Mae Chaem weather stations, recorded from (1/1/1979) to (31/12 /2016)	- Meteorological department	- Weather station
<ul style="list-style-type: none"> <li>Precipitation</li> </ul>	- The precipitation collected from Mae Chaem weather stations, recorded from (1/1/1979) to (31/12 /2016)	- Meteorological department	- Weather station
<ul style="list-style-type: none"> <li>A2 B2 climate scenario</li> </ul>	The daily temperature and precipitation from (1/1/2016) to (31/12/2031)	- SEASTART	- Weather station
<b><u>Observed data</u></b>			
<ul style="list-style-type: none"> <li>Runoff</li> </ul>	- The daily runoff at hydrology station P14A recorded from (1/1/2010) to (31/12/2016)	-Upper Northern Region Irrigation Hydrology Center	- Calibration & Validation

### **Landuse changes scenarios**

Landuse changes in this study shall be divided into 3 scenarios, where each scenario is an assumption as follow.

#### **Present landuse**

The first scenario is the base year of a present landuse (2015) which shall be simulated base on landuse map in Mae Chaem watershed.

#### **A huge agriculture expansion**

In this scenario the researcher assumed that there is an increasing in agriculture in Mae Chaem watershed. The total amount of agricultural area increase is equal to the amount of forest area left at present, meaning that all available forest area shall be converted to an agricultural area.

#### **Reforestation**

In this scenario the researcher assumed that there is an increasing in forest conservation in Mae Chaem watershed. The total amount of forest area increase is equal to the amount of agricultural area left at present, meaning that all available agricultural area shall be converted to forest area.

### Climate change scenarios

The titles of the storylines have been kept simple: A2 and B2 described by Sangmanee et al. (2010) as follow:

#### A2 Climate scenario

A2 climate scenario was selected to represent an upcoming monthly weather forecast. To illustrate the underlying theme is self-reliance and preservation of local identities, where economic growth and technology are gradually developed. Values of A2 climate change consist of precipitation (rainfall in mm.) and temperature (degree celcius).

#### B2 Climate scenario

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

### Applying SWAT model for runoff simulation

Before simulate runoff from SWAT model. SWAT model require a calibration, in order to get the closet and harmonize with the observed data in both runoff and sediment. Parameters in SWAT model shall be adjusted by SWAT-CUP, then the best parameters shall be readjusted to SWAT model. After the calibration is done, validation is required. When calibration and validation are done, SWAT model is applicable.

#### Calibrate and Validation

The monthly observed runoff for calibration and validation are retrieved from hydrology station P14A which locate at Hot district Chaing Mai. Coefficient of determination ( $R^2$ ) and Nash-sutcliffe efficiency ( $E_{ns}$ ) shall be evaluate.

### Results

SWAT parameters are calibrated via SWAT – CUP as show in table 2. These streamflow-related parameters are frequently used for SWAT model calibration, summarized by (Douglas-Mankin et al., 2010).

**Table 2** Parameters adjusted in SWAT-CUP

Parameters	Detail	Old Value	New Value	Changes %
CN2	CN2 or runoff curve number is a value which identify an efficiency of runoff flow in accordance with land cover. Range from 35 - 98.	77	85.316	+10.8%

**Table 2** Parameters adjusted in SWAT-CUP (Cont.)

Parameters	Detail	Old Value	New Value	Changes %
ALPHA BF	A constant value which direct variation to groundwater recharge. Range from 0.1 - 0.3	0.48	0.006	-98.5%
GW DELAY	The delay time consume in permeability process. Range from 0 - 500	31	500	+1512%
GWQMN	The initial value of water in aquifer. (Groundwater will reach surface water when a water level is greater or equal to GWQMN). Range from 1 - 1000.	1000	1.95	-99.8%

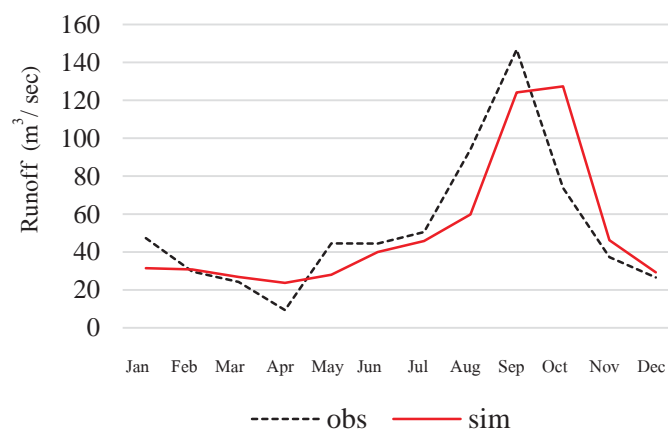
The calibration data is a monthly observed runoff from hydrology station P14A during January – December 2014 as shows in table 3. The satisfactory of ( $R^2$ ) and ( $E_{ns}$ ) are greater or equal to 0.6 and greater or equal to 0.5 (Arnold et al., 2012) respectively.

**Table 3** Monthly comparisons between observed runoff and simulated runoff at hydrology station P14A

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014												
Obs	47.28	29.69	24.22	9.37	44.53	44.41	50.47	94.13	146.81	73.78	37.26	26.51
Sim	31.47	30.73	26.78	23.64	27.97	40	45.81	59.79	124.2	127.4	46.2	29.27

**Calibration result**

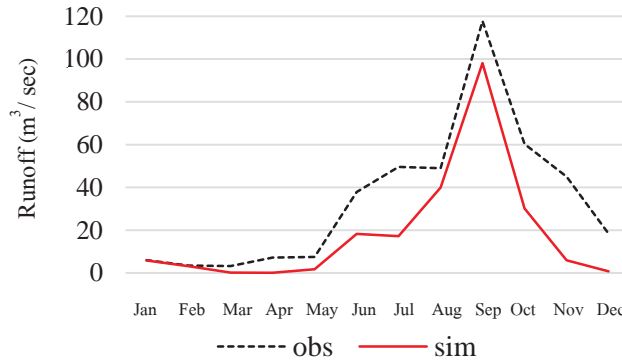
After compare a simulated runoff with an observed runoff as shows in figure 1 during January - December 2014 (via SWAT - CUP), the analysis reveals that Coefficient of determination ( $R^2$ ) and Nash-sutcliffe efficiency ( $E_{ns}$ ) are 0.67 and 0.65 respectively.



**Figure 1** A graph shows observed runoff and simulated runoff (Calibration)

**Validation result**

In validation process observed runoff and simulated runoff are compared as shows in figure 2 by which the period of observed runoff is January - December 2016 (via SWAT - CUP), the analysis reveals that Coefficient of determination ( $R^2$ ) and Nash-sutcliffe efficiency ( $E_{ns}$ ) are 0.86 and 0.62 respectively.

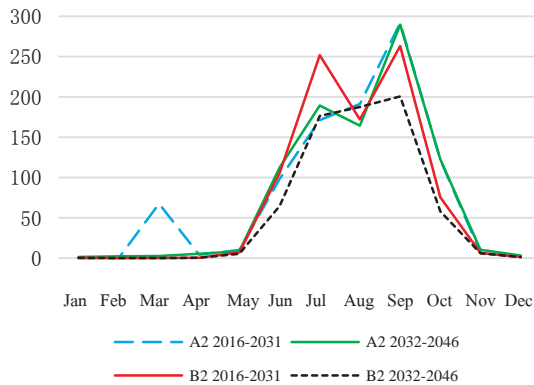


**Figure 2** A graph shows observed runoff and simulated runoff (Validation)

Therefore, both calibration and validation were satisfied. SWAT is applicable for estimate both runoff and sediment in accordance with landuse changes in Mae Chaem watershed under climate change scenarios.

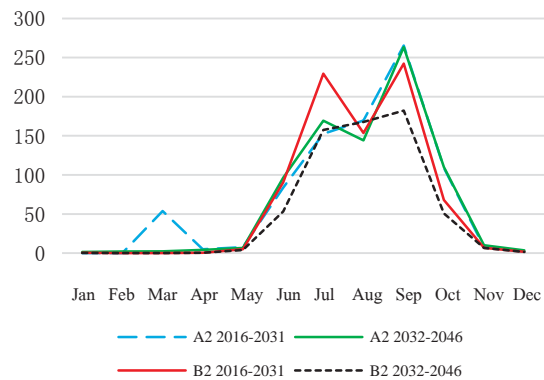
**Landuse changes and runoff**

A present landuse (53.94%)



**Figure 3** Simulated runoff in present landuse under A2 and B2 climate changes

A fully reforestation (0%)



**Figure 4** Simulated runoff in fully reforestation under A2 and B2 climate changes

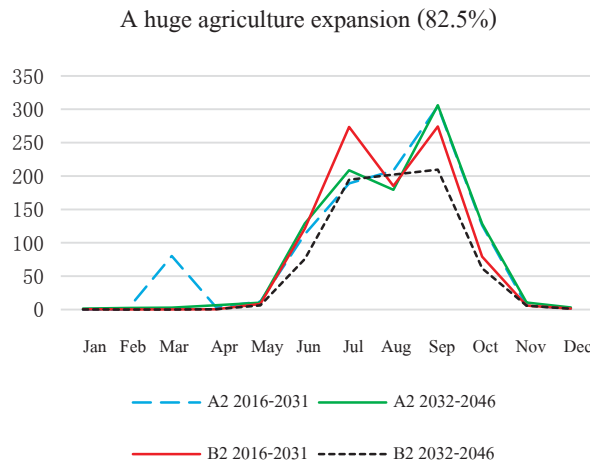


Figure 5 Simulated runoff in huge agriculture expansion under A2 and B2 climate changes scenarios

Table 4 Simulated runoff in accordance with landuse changes in Mea Chaem watershed under climate change scenarios

Climate Scenario	Landuse	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (m <sup>3</sup> /year)
A2 2016-2031	Present landuse (53.94%)	0.06	0.05	67.45	4.17	10.09	98.14	171.20	191.20	291.50	122.00	6.63	1.63	964.12
	Reforestation (0%)	0.07	0.06	53.76	4.88	7.69	83.62	152.60	169.60	265.40	109.10	7.70	1.91	856.39
	Agriculture expand (82.5%)	0.05	0.05	80.16	3.52	12.00	112.80	189.00	208.10	304.40	126.30	5.93	1.46	<b>1043.78</b>
A2 2032-2046	Present landuse (53.94%)	1.46	2.26	2.58	5.46	8.69	112.40	189.30	164.20	289.70	122.60	10.41	3.19	912.25
	Reforestation (0%)	1.52	2.16	2.33	4.16	6.70	96.43	169.30	144.20	263.30	110.00	10.02	3.45	813.57
	Agriculture expand (82.5%)	1.43	2.33	2.73	6.33	10.22	128.70	208.60	179.30	<b>306.1</b>	128.60	10.49	3.00	987.82
B2 2016-2031	Present landuse (53.94%)	0.49	0.12	0.15	0.44	6.98	105.60	251.70	172.10	263.10	75.52	6.37	1.46	884.04
	Reforestation (0%)	0.56	0.14	0.16	0.46	5.06	90.46	229.30	153.60	242.20	67.96	6.91	1.69	798.51
	Agriculture expand (82.5%)	0.44	0.11	0.14	0.44	8.37	121.20	273.40	185.20	274.10	79.27	5.94	1.30	949.91
B2 2032-2046	Present landuse (53.94%)	0.18	0.04	<b>0.02</b>	0.39	5.39	64.50	176.30	187.50	200.50	58.00	6.11	1.33	700.26
	Reforestation (0%)	0.22	0.05	0.03	0.41	4.05	53.24	157.50	167.70	182.20	50.81	6.55	1.54	<b>624.29</b>
	Agriculture expand (82.5%)	0.15	0.03	<b>0.02</b>	0.39	6.27	75.65	194.50	202.20	209.50	61.85	5.71	1.18	757.45

Figure 3 - 5 the simulation runoff in each landuse change scenario under A2 and B2 by which the period of A2 and B2 climate scenarios were split into two periods (2016 - 2031 and 2032 - 2046). From table 3 the result reveals that, the highest runoff occurs in September (306.1 m<sup>3</sup>/sec) under A huge agriculture expansion landuse under A2 2016-2032 climate change. The lowest runoff occurs in March (0.02 m<sup>3</sup>/sec) in accordance with both Present landuse and A huge agriculture expansion landuse under B2 2032-2046 climate change.

Table 4 shows that the second scenario (Reforestation under A2 and B2 climate scenario) gives the lowest runoff which are 856.39, 813.57, 798.51 and 624.29 m<sup>3</sup> / sec. For the first scenario (Present landuse under A2 and B2 climate scenario) gives a moderate runoff which are 964.12, 912.25, 884.04 and 700.26 m<sup>3</sup> / sec. For the third scenario (Huge agriculture expand under A2 and B2 climate scenario) gives the highest runoff which are 1043.78, 987.82, 949.91 and 757.45 m<sup>3</sup> / sec .

### Discussion

As the result shows that, in a situation with an increasing in agriculture area cause an increasing in runoff. This result relates to a study of Wuttichaikitcharoen (2013) when forest is converted to an agriculture area, the ability of plant uptake decrease. Water yield has a decrease of 1.8 percent in the forest landscape scenario and an increase of 4.2 percent in the agriculture-rich scenario (Sun et al, 2015). It also proofs that a forest cover loss is accompanied by an increased stream discharges and surface runoff (Guzha et al, 2018). Water demand from maize crop is less than tree's demand which lead to a higher runoff in a scenario with a more agriculture area. The impacts of climate change under A2 scenario and landuse change is prior to (Pervez & Henebry, 2015) that runoff is projected to increased by 10% annually when the area of forest is reduced under A2 climate.

It is obvious that, the total runoff shall response differently among landuse. These responses are determined by a hydrological process of interception, infiltration, evapotranspiration, and groundwater (Lin et al, 2015). Conversion from agriculture (except orchard) to forest usually increases evapotranspiration rate and soil infiltration capacity, which lead to a reduction in total runoff (Lin et al, 2012).

### Conclusions

The impact on runoff from landuse change under A2 climate scenario was estimated, while landuse change scenarios were assumed by changing from an agriculture area to a forest area and vice versa. The assumption of landuse changes were defined as a. 0% of agriculture area (all agriculture area was converted into forest area) b. 53.94% of agriculture area (forest area remained at 28.56%) and c. 82.5% of agriculture area (all forest area was converted into agriculture area)

Before using SWAT model to simulate runoff, calibration and validation are required. The result shown that both coefficient of determination (R<sup>2</sup>) and nash-sutcliffe efficiency (E<sub>ns</sub>) have reached the satisfactory standard at 0.67 and 0.65 for calibration, and 0.86 and 0.62 for validation, while calibration period is January-December 2014 and January-December 2016 for validation.

The evaluation on the impact from each landuse change scenario reveals that, a huge agriculture expansion scenario (82.5% of agriculture: no forest area) generate the most annual runoff (1043.78) while a reforestation scenario (82.5% of forest: no agriculture area) generate the least annual runoff (856.39)

### Acknowledgements

This article was a part of the research project entitled “Estimation of the climate variability impacts on maize production/maize seed and integrated farming system: a case study of Mae Chaem basin, Chiang Mai province”, and was funded by The Thailand Research Fund (TRF) and Knowledge Network Institute Of Thailand (RDG6020014). Furthermore, the authors would like to thank the reviewers for their helpful comments to improve the manuscript.

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