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Paddy Response to Ozone: A Comparison between an Industrial and Residential Area in Malaysia

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Abstract

Numbers of studies have reported that ozone brings many adverse and crucial effects on paddy. Ozone which is a secondary pollutant is created by the action of the short wavelength radiation from the sun on its anthropogenic precursors. The sources are usually coming from the industrial and vehicular emissions. In Malaysia, paddy fields are located near to the residential areas. The sources of air pollution for these two areas are different, where the industrial area is usually associated with the emissions from the factories and the vehicles while residential area is only focused on the vehicles emissions. Thus, this study was carried out to identify the differences of the paddy reduction between industrial and residential areas in Malaysia by adopting the AOT40 index materials and improvising them depending on the Malaysia actual air quality and paddy data. The results showed that the paddy reduction in the industrial area during main and off seasons was higher compared to the residential area. The industrial area contained more phytotoxic gases than the residential area which lead to the higher reduction in the paddy production. Besides, the paddy reduction during the off season was higher in both areas, compared to the main season. This situation happened perhaps due to the increasing in stomatal conductance and the ozone uptake by leaves during the monsoon season, which resulted in more paddy yield loss.

Keywords: AOT40, concentration, *Oryza sativa*, ozone, yield loss

1. Introducation

Paddy (*Oryza sativa*) is one of the staple crops in Southeast Asia including Malaysia (Gosh & Bhat, 1998). Its consumption is increasing every year as the population increases. However, many studies reported that paddy production had been decreasing due to the increased air pollutant especially ozone. According to Emberson et al. (2009), the modelling based studies suggested that the agricultural crops yield might decline approximately about 5 to 20% in Asia and more common in areas with elevated ozone concentrations.

The ground level of ozone is an atmospheric pollutant that encompasses phytotoxic gases, which have much potential to bring adverse impacts on plants in the agricultural regions (Emberson et al., 2009). Ozone is phytotoxic to plants due to its ability that can decrease the metabolism rate in the plants and significantly reduce the productions (Calatayud, Iglesias, Talon, & Barreno, 2004). Ozone which is a secondary pollutant is created by the action of the short wavelength radiation from the sun on its anthropogenic precursors. The sources are usually coming from the nitrogen oxides and volatile organic compounds, emitted by industrial and vehicular emissions of (Abdul-Wahab, Bakheit, & Al-Alawi, 2005).

In Malaysia, paddy fields are located in almost every state. However, each state in Malaysia has different types of land use like industrial area, residential, and others. , this study was carried out to identify the differences of the paddy reduction between the industrial and the residential areas in Malaysia. The Accumulated Exposure Over a Threshold of 40 ppb (AOT40) was used as the guideline in calculating the paddy reduction. The AOT40 index is a cumulative exposure index, which is calculated as the sum of the differences between the hourly concentration (in ppb) and 40 ppb for each hour when the concentration exceeds 40 ppb (United Nations Economic Commission for Europe, 1999). This index is based on the ozone concentration level.

According to the European guideline, 5% reduction of the agricultural crops yield will be anticipated to occur if the accumulated ozone concentration is above 40 ppb within 3 months is above 3000ppb.h. (Ishii, Bell, & Marshall, 2007). Therefore, the AOT40 index materials was adopted and improvised in conducting this study, depending on the Malaysia scenarios and the actual air quality record.

2. Method

2.1 Study Area and Mateorolgy

The analysis was based on the two monitoring stations located in Kedah and Perak, as shown in Figure 2.1. Kedah is representing the residential area while Perak is the industrial area (Department of Environment, 2010).

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Notes:

- All the ozone concentration data and paddy production records were obtained from each monitoring stations.
- Both of the data were located in the same regions.
- Each of the paddy plantations area is near to the monitoring station.
- The height of ozone detector is 2-3m from the ground, which is fit for the purpose to measure the ozone concentration in order to estimate the paddy reduction

Figure 2.1. Location of monitoring stations in Malaysia

Generally, Malaysia is notorious to experience high humidity. The mean relative humidity varies from as low as 72% to as high as 87% (Malaysian Meteorological Department, 2008). The minimum relative humidity is normally found in the months of January and February while the maximum is generally found in the month of November (MMD, 2008). The temperature in the study area is usually between 27°C and 30°C during the daytime and 22°C to 24°C during the night time (MMD, 2008).

According to MMD (2008), Malaysia is normally divided into two monsoon seasons, i.e. The South-west monsoon and the North-east monsoon. The South-west monsoon usually begins in the 15th of May or early June until the end of September while the north-east monsoon starts on early November until March. The South-west monsoon exhibits drier air with higher temperature and less rainfall, as compared to the other months when it receives more rainfall during the north-east monsoon (MMD, 2008).

The monthly rainfall pattern shows that the two periods of the maximum rainfall is separated by the two periods of the minimum rainfall (Jamaludin, Sayang, Wan, & Abdul, 2010). The primary maximum is commonly occurred from October to November while the secondary maximum is normally occurred from April to May. The primary minimum takes place from January to February and the secondary minimum is from June to July (Jamaludin et al., 2010).

2.2 Ozone and Crops Data

The quality assured data of ozone was collected by the continuous monitoring stations which are located in Bakar Arang (Kedah) and Ipoh (Perak), as shown in Figure 2.1. Data was provided by the Department of Environment (DoE) Malaysia. The data is regularly subjected to standard quality control processes and quality assurance procedures by the DoE (DoE, 2010a). The period of data was observed continuously from January 2004 to December 2009 and recorded on the hourly basis from 7a.m to 7p.m every day.

Samples of the ozone concentrations were collected by using a UV Absorption Ozone Analyzer Model 400A (EPA Approved EQOA 0992–087). The model 400A UV Absorption Ozone Analyzer, is a microprocessor controlled analyzer that uses a system based on the Beer–Lambert law for measuring the low ranges ozone in the ambient air (DoE, 2010b).

The agricultural crop, paddy (*Oryza sativa*) was recorded from 2004 to 2009 for every selected site as shown in Figure 2.1. Paddy was used in estimating the reduction of agricultural crops production due to the effects of ozone concentration level. The crops data was obtained from the Department of Agricultural (DoA) Malayisa. In Malaysia, there are two seasons for paddy plantation; the main seasons and the off seasons (Department of Agriculture, 2010a). The main season (July to September) is the period when paddy is grown without depending wholly on any irrigation system while the off season period (March to May) is where the paddy plantation is depending on the irrigation system (Department of Agriculture, 2010b).

2.3 Mathematical Models

AOT Index is calculated according to the variance between X ppb and hourly ozone concentrations, in which ozone concentration must exceed X ppb. This index is calculated using Equation 2.1, where the ozone concentrations used are during day time (7 am – 7 pm) with the global radiation more than 50 Wm^{-2} for a period of 3 months.

$$\text{AOTX}=\sum_{i=1}^{n}\left[C_{O_3}-X\right]_i \quad for \ C_{O_3} > X \ ppb \ [unit : ppb.h] \qquad (2.1)$$

Where, C_{O_3} is the hourly ozone concentration in ppb, *i* is the running index, and *n* is the number of hours with C_{O_3} more than X ppb, during the time appraisal (Grunhage, Jager, Haenel, Lopmeier, & Hanewald, 1999).

Malaysia has two seasons (main and off season) for paddy plantation. Therefore, the percentage of paddy reduction for each AOTX index for both seasons was then calculated using the formula shown in equation 2.2.

$$\text{Calculated paddy reduction (\%)} = \frac{\text{AOTX value}}{\sum \text{Ozone Concentration}} \ \text{x} \ \text{Paddy production} \qquad (2.2)$$

Where, *X* is the index of AOT.

The calculation was conducted using the Microsoft Office Excel 2007.

The AOT40 index which is calculated based on the standard in the European standard stated that 5% reduction in yield for agricultural crops will be expected to occur if the accumulated of ozone concentration within that duration is above 3000ppb.h (Ishii et al., 2007; Long-range Transboundary Air Pollution Convention, 2004). Therefore, the analysis using the Equation 2.3 was carried out, to identify the possible crop reduction that likely to occur in Malaysia. In this analysis, 3000ppb.h was used as the critical level, similar to the European concentration-based critical level (LRTAP Convention, 2004).

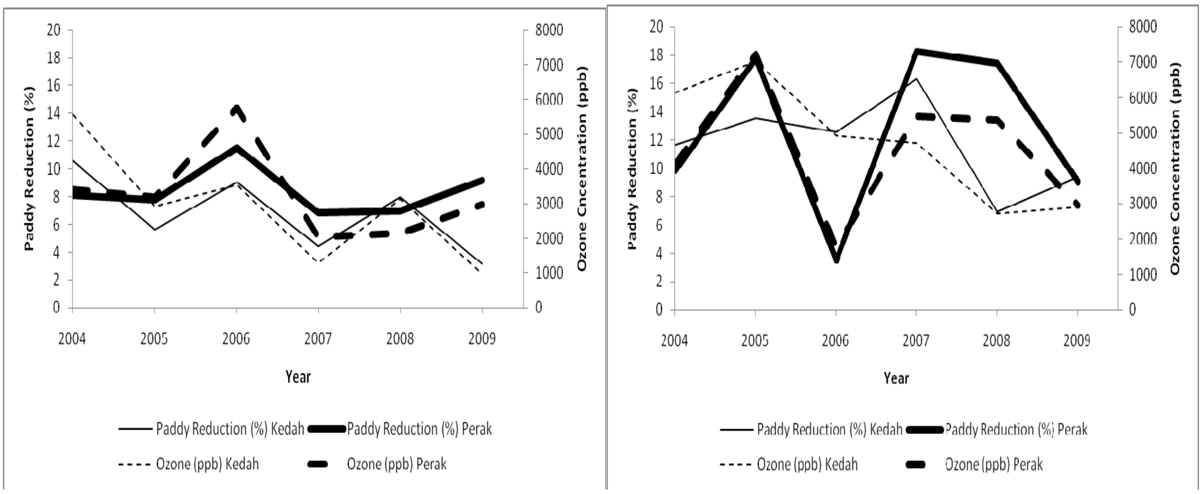
$$\begin{array}{c}\text{Estimated}\\ \text{crops reduction (\%)}\end{array} = \frac{\text{Calculated crops reduction (calculation) (\%) x 3000ppb.h}}{\text{Total AOTX (ppb.h)}} \qquad (2.3)$$

Where, 3000ppb.h is the European concentration-based critical level for the AOT40 index (United Nations Economic Commission for Europe, 1996). Therefore, to investigate the crops reduction for all AOTX indexes, 3000 ppb.h is employed as the guideline consistent with the European critical level. The estimated crops reduction was calculated based on the total ozone exposure for both seasons and the crops production record (2004 to 2009).

Studies by Fuhrer et al. (1997) showed that the AOTX indexes were close to the linear relationship. Therefore, the relationship between the paddy reduction and the ozone concentrations were tested using the linear regression analysis. The correlation coefficient, R^2, between the parameters were calculated and compared. This analysis was done using SPSS Version 11.5.

3. Results and Discussions

The analysis on the differences between paddy reduction in the industrial and the residential areas was carried out for main and off seasons. Figure 3.1 illustrates the paddy reduction between Perak and Kedah, from 2004 until 2009.



(a) (b)

Figure 3.1. (a): Main season, (b): Off season: Paddy reduction between residential area (Kedah) and industrial area (Perak) in Malaysia

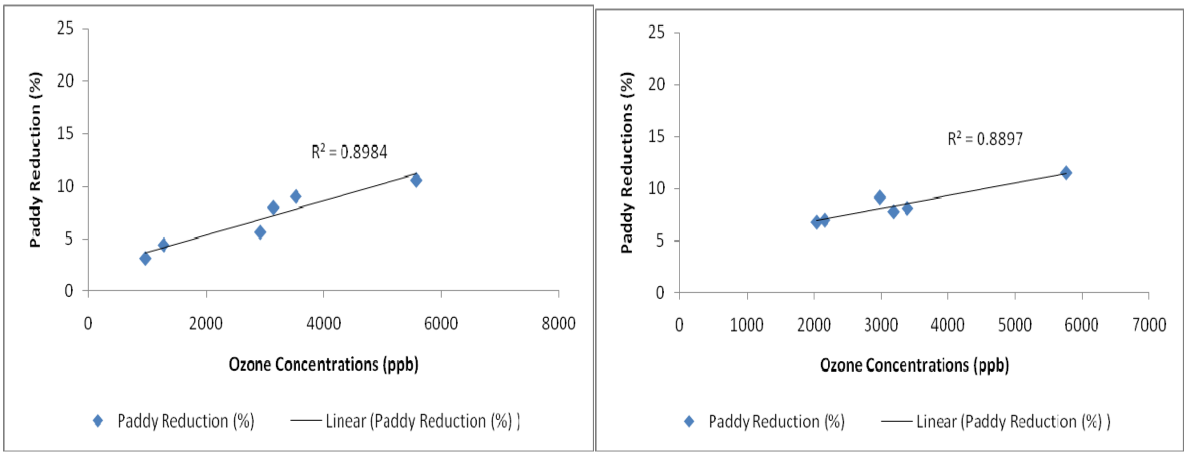
In Figure 3.1, the paddy reduction in Perak during both seasons was higher as compared to Kedah. The highest paddy reduction during the main season was 12% while the off season was 18%. The higher reduction in this area was due to the higher pollutant concentrations in the atmosphere. In the industrial area, it was not only associated with the factories emission but the vehicles emissions as well. Thus, the industrial area contained more phytotoxic gases than the residential area which lead to the higher reduction in the paddy production (Krupa et al., 1988, M. Rao & H. Rao, 1989).

The DoE Malaysia had categorized the sampling station in Kedah as the residential area. In this area, there was no source of industrial emission near the sampling station. Therefore, the focal source of air pollution in the residential area was coming from the vehicles emission. Results from Figure 3.1 illustrates that although the pollutants emitted from the vehicles were lower than the factories emissions, yet can still cause the paddy production reduction.

Figure 3.1 also demonstrates that the paddy reduction during the off season was higher in both areas, compared to the main season. In Malaysia, off season of paddy yield is usually during the north-east monsoon. This season has a higher humidity in these areas due to the heavy rainfall. Although the rainfall tends to wash out the pollutants including ozone, higher humidity and mild temperature can increase the stomatal conductance in paddy, which later lead to the higher losses in paddy yield (Lal, Naja, & Subbaraya, 2000 ; Wang, Kiang, Tang, Zhou, & Chameides, 2005).

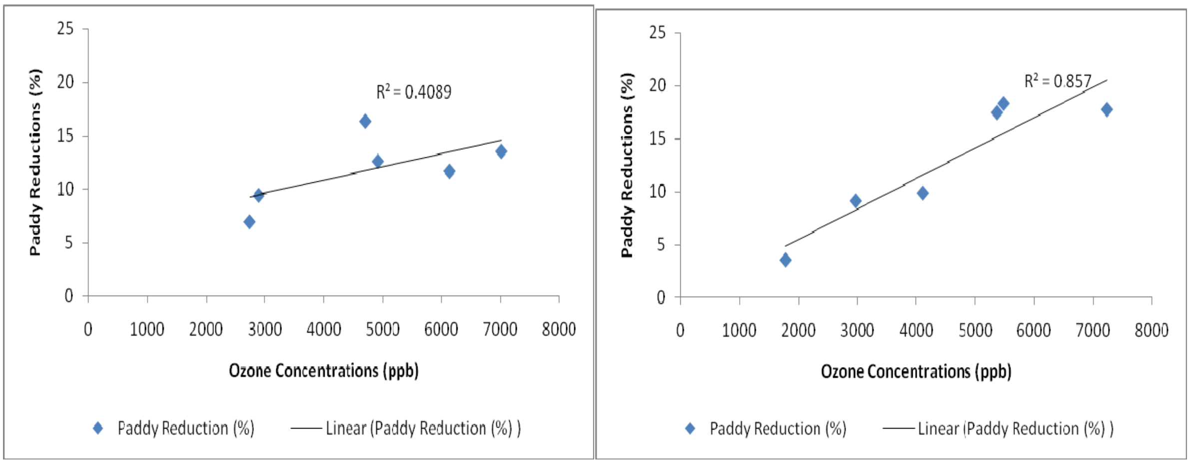
The relationship between the paddy reduction and the ozone concentrations for both selected sites were tested using the linear regression analysis. Figure 3.2 illustrates the R^2 value for the relationship between the paddy reduction and the ozone concentration from 2004 to 2009 during the main seasons.

Figure 3.3 illustrates the R^2 value for the relationship between the paddy reduction and the ozone concentration from 2004 to 2009 during the off seasons.



(a) (b)

Figure 3.2. (a): Kedah, (b): Perak: Relationship between paddy reduction and ozone concentrations from 2004 to 2009



(a) (b)

Figure 3.3. (a): Kedah, (b): Perak: Relationship between paddy reduction and ozone concentrations from 2004 to 2009

Figure 3.2 and Figure 3.3 demonstrate the R^2 values for the correlation between the paddy reduction and ozone concentrations for the main season and the off season in Kedah and Perak. Based on the figures, the R^2 values for Kedah during the main season and off season are 0.8984 and 0.4089, respectively. The R^2 values for Perak are 0.8897 during the main season and 0.857 in the off season. The R^2 values in the analysis were closer to 1 except for Kedah during the off seasons. However, R^2 value of 0.4089 is still can be classified as medium fit and acceptable in simulating the data (Abraham & Ledolter, 2006). Therefore, the R^2 values obtained from the analysis indicated that the ozone concentration in the atmosphere could have an adverse impact to the paddy production and can be identified as one of the factor that can threaten the paddy yield.

4. Conclusions

The results illustrated that the paddy reduction in the industrial area was higher as compared to the residential area. It was due to the higher level of air pollutant in the industrial area than the residential area. Factory emitted more ozone's precursor which leads to the higher level of ozone concentration in the air, compared to the vehicles emission. The results also exemplified that the paddy reduction during the off season was higher for both areas although during the rainy season. Even though rainfall has the ability to cleanse the air by removing air pollutants including ozone that is suspended in the atmosphere, it also increases the stomatal conductance in paddy. This significantly reduces paddy production. The regression analysis demonstrates that the ozone concentration could cause the paddy reduction in Malaysia.

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