AOTX INDICES IN RESPONSE TO THE CROPS YIELD UNDER THE MALAYSIA CLIMATE

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ABSTRACT

Ground level ozone (O_3) is an atmospheric pollutant that encompasses a phytotoxic gas, which has much potential to cause adverse impacts on plants in the agricultural regions. The purpose of this study was to look at the contributions of ozone to Accumulated exposure Over a Threshold of X ppb (AOTX) indices in response to the crops yield, under the Malaysia climate. Besides that, estimation of rice (*Oryza sativa*) reduction in Kedah, ('rice bowl' of Malaysia) due to ozone exposure was calculated based on the European benchmark. Environmental parameter that was used in this study was ozone concentration. These data were observed from 7a.m to 7p.m every day. However, the most critical AOTX index due to crops reduction that is suitable for Malaysia climate is still under investigation. According to the European benchmark, for AOT40 values above 3000 ppb, a 5% of yield loss is anticipated to occur. Based on the study, the value of AOT40 illustrates that the most of the months in year 2004 had exceeded the European benchmark. Thus, approximately, 1.60 tonnes per hectare of paddy yield loss occurred in year 2004. This data concluded that the ozone exposure to crops will reduce the production of the paddy.

Keywords: *AOT40, crops reduction, ozone, phytotoxic*

1. INTRODUCTIONS

In recent decades, particularly, the tropospheric concentrations of ozone have become a major concern for human and forest health, and biodiversity as well. Ozone concentrations have been increasing gradually during the past 100 years, with the greatest shift in the 1980's [1]. Studies regarding the effect of ozone on plants also have caught many attentions around the world as ozone encompasses a phytotoxic gas, which has much potential to cause adverse impacts on plants. The phytotoxicity of ozone is due to its high oxidative capacity, which it can weaken the metabolism of plants and lead to yield reduction in the agricultural crops [2]. According to Heck et al., [3] ozone can cause significant yield losses on the sensitive crops species by contaminating the water intake and nutrient supplies.

For over many years, air pollution experts have explored many mathematical approaches to summarize the ambient air quality information in the biologically meaningful forms, in order to comprehend the relationship between the ozone exposure and vegetation effects. One of the main focuses of using the exposure as an index is the ozone uptake may be decoupled from the time period when the highest ozone concentrations occur. Currently, Accumulated exposure Over a Threshold of 40 ppb (AOT40) is the most practical index that has been utilized in identifying the exposure-response relationship.

However, Grünhage et al., [4] suggested that concentration-based exposure indices may not be appropriate for the use in the ozone risk assessments. In the text of Gothenburg Protocol [5] it was also recommended that AOT40 values should be replaced by flux oriented quantities. This idea is formed due to the effects of ozone on plants are more directly related to the effective dosage, such as the amount of ozone that is taken up per unit of leaf surface and time. In contrast, under the field conditions, the highest concentrations of ozone, which has the greatest weight in many exposure indices, may not be associated with the highest flux if it occurs in less turbulent atmospheric conditions. Therefore, the factors, which influence the flux of ozone to the vegetative surface, should be considered.

Although the importance of the effective dose concept has been well recognized, the link between the ozone flux and the plant response has been established very rarely and the database for the derivation of the critical loads of ozone is very inadequate [6]. In the previous study done, the critical levels for the long-term effects of ozone have been designed based on the mean concentrations over a given period of time, for instance, the arithmetic mean, growing season, and daily mean concentrations during a defined 7 hrs period. The use of mean concentration completely however, gives an equal weight to all concentrations and ignores the length of the exposure. Currently, with a limited European exposure-response data and the difficulties to mapping or modelling the complex exposure indices accurately, the procedure that is depending on the definition of a cut-off concentration becomes more practical. Therefore, AOT40 is still relevant in order to estimate the effects of ozone on crops.

However, as most of the studies done on AOT40 were performed in Europe, Mediterranean, and America regions, this index does not consider the climatic difference in other region that might affect the ozone sensitivity due to the different rates of plant growth or different cut-off concentration (Accumulated exposure Over a Threshold of X ppb (AOTX)) such as 40nmol mol $^{-1}$ in AOT40 [7]. Therefore, the setback of this index to be employed in Asia is due to the incompatibility crisis. This argument is raised because the lack of attained data and the trivial number of studies have been addressed with reference to the compatibility subject.
The aims of this study was to look at the contributions of ozone to Accumulated exposure Over a Threshold of X ppb (AOTX) indices in response to crops yield, under the Malaysia climate and to estimate the rice (Oryza sativa) reduction in Kedah, Malaysia due to the ozone exposure based on European benchmark.

2. MATERIALS AND METHODS

2.1 Study Area and Local Meteorology

Kedah is located in the north of Peninsular Malaysia, covering an area of 9426km^2. This area consists of 12 districts; Kota Setar (N 6° 10', E100° 30'), Kuala Muda (N 5° 31', E100° 2'), Kulim (N5° 22',E 100° 34') Baling (N 5° 40', E 100° 55'), Kubang Pasu (N 6° 19' 60",E 100° 26'), Yan (N 5° 52', E 100° 24') , Sik (N6° 0' ,E 100° 49'), Pendang (N 6° 0' , E 100° 28'), Padang Terap (N6° 15', E 100° 39'), Langkawi (N 6° 19' , E 99° 45') , Bandar Baharu (N 5° 7' 60 , E 100° 30') ,and Pokok Sena (N 6° 10' ',E 100° 31' 60) (Figure 1). The population in this state is approximately 1.9 million in 2010. This region is regarded as focal point of paddy growth in Malaysia as it produces one third of Malaysia’s total rice production.

Figure 1: Map of Kedah

According to Malaysia Meteorological Services (MMS), Kedah is generally governed by two monsoon seasons, which are south-west monsoon and north-east monsoon. South-west monsoon usually starts in the later half of May or early June till the end of September and north-east monsoon starts from early November till March. During south-west monsoon, this area is drier with higher temperature and less rainfall as compared to the other months when it receives heavy rainfall during the north-east monsoon [8]. Temperature in the study area is usually between 27 to 30 °C during the daytime and 22 to 24°C during the night time [9].

2.2 Air Quality Data

There are three continuous air quality monitoring stations in this state, located at Langkawi (N06°19.903, E099°51.517), Alor Setar (N06°08.218, E100°20.880), and Sungai Petani (N05°37.886, E100°28.189). However, this study only focused at Sungai Petani, as this area is largely surrounded by paddy field compared to the other two stations.

Ozone monitoring record from Department of Environment (DoE), Malaysia was used to predict the ozone contribution to AOTX indices. The quality assured data of the ozone was provided by DoE. The data are regularly subjected to standard quality control processes and quality assurance procedures by the DoE. The records used were for 2004, which were observed hourly from 7a.m to 7p.m every day. Samples of ozone concentrations were collected by using 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 low ranges of ozone in ambient air.

2.3 Analytical Procedures

The first analysis is to calculate the exposure indices, AOTX. AOTX is a cumulative exposure index, which is calculated during light hours (7a.m to 7p.m) as the sum of the differences among the hourly concentration (in ppb) over a time period of three months and X ppb for each hour when the concentration exceeds X ppb [5].

$$\text{AOTX} = \sum_{i=1}^{n}\left[C_{O_3} - X\right]_i \ for\, C_{o_3} > X \ ppb[unit: ppb.h] \quad (1)$$

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 evaluation [10].

The second analysis is to estimate the loss of rice (*Oryza sativa*) due to the ozone exposure in year 2004 by using the secondary data. According to the European benchmark, for AOT40 values above 3000 ppb, there is a 5% of yield loss occurred. Therefore, yield losses calculation was conducted by using Microsoft Office Excel 2007.

3. RESULTS AND DISCUSSIONS

3.1 Ozone Concentrations and AOT40

In Table 1, ozone concentrations that contributed to AOT40 were calculated in a three- months period, from 7a.m to 7p.m.

Table 1: Values of AOT40 for the three months period in 2004 in Kedah, Malaysia

Period	AOT40 (ppb)
January 2004 March 2004	4446
February 2004 to April 2004	6997
March 2004 to May 2004	6677
April 2004 to June 2004	7618
May 2004 to July 2004	6346
June 2004 to August 2004	6675
July 2004 to September 2004	6532
August 2004 to October 2004	5865
September 2004 to November 2004	3747
October 2004 to December 2004	1163

According to Table 1, AOT40 value from April to June 2004 was the highest when compared to other period with 7618ppb. October to December 2004 recorded the lowest value of AOT40 with only 1163ppb. According to the meteorological condition, north-east monsoon, which provides heavy rainfall to the study area, begins on November every year. This explains the low AOT40 value during this period.

Rainy season will lessen the presence of UVB, reduce temperature level, and increase the humidity, which leads to a low ozone transformation. Besides that, rainfall cleans the atmosphere thus removes away the pollutants such as the nitrogen dioxides, the precursor of ozone. This phenomenon is observed clearly in the reduction of the ozone concentration during the raining period as reported by Pudasainee et al. [11]. During rainy days, insufficient solar radiation and the washout of pollutants resulted in near absence of photochemical ozone transformation [12]. Therefore, formation of ozone can be influenced by the meteorological parameters, for instance, temperature and UVB. High temperature and UVB will favour the formation of ozone, which is a photochemical species [13].

As AOT40 from April to June 2004 gave the highest value, graph of the AOT40 in Kedah, Malaysia from April to June 2004 has been plotted and the result is as shown in Figure 2.

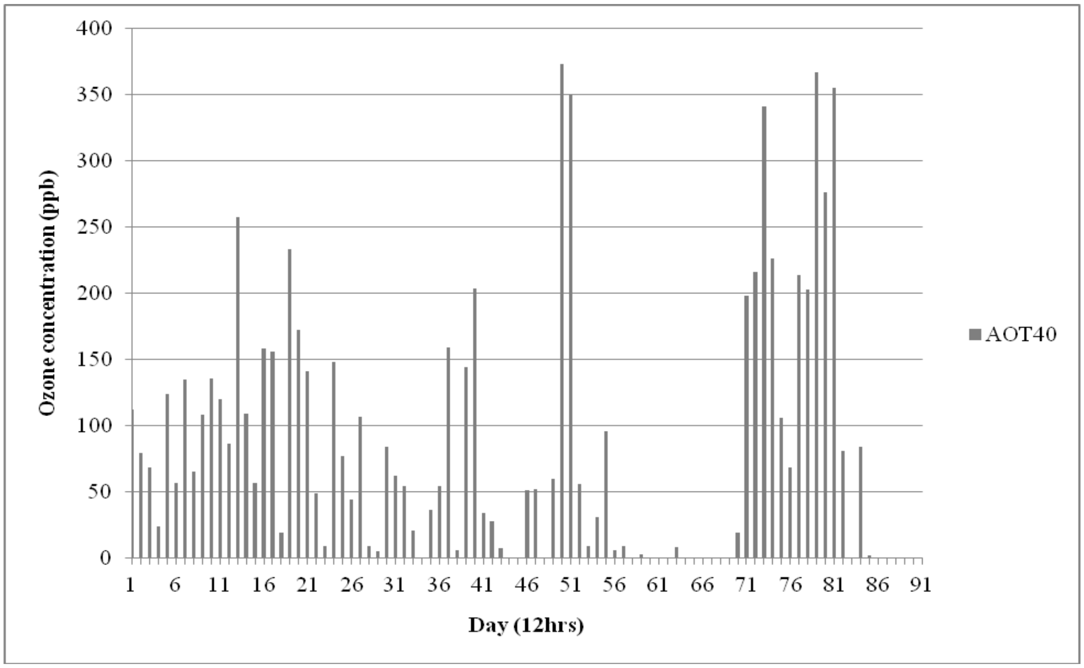

Figure 2: AOT40 for Kedah, Malaysia from April to June, 2004

The total of AOT40 for this region within these three months was 7618ppb, which has exceeded the European benchmark of 3000ppb. According to the benchmark, crop yields could be reduced by a minimum of 5% if the accumulated ozone concentrations were above 3000ppb [14]. Thus, all crop yields in Kedah are perhaps being highly affected by the ozone exposure. Figure 2 shows the AOT40 value for this region is highly exceeded the European Benchmark. Therefore, it was estimated that the crops yield loss will be almost doubled with yield loss of 10% due to the high ozone exposure

3.2 Ozone Concentrations and AOTX

In Table 2, ozone concentrations that contribute to AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 were calculated. This calculation was based on 12 hrs daylight period (7a.m to 7p.m) from April to June 2004, as this three months period gave the highest AOT40 values compared to the other three months period throughout year 2004.

Table 2: Values of AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50, from April to June 2004 in Kedah, Malaysia

Ozone concentration(ppb)	AOTX	AOT value (ppb)
51949	AOT 0	37193
51949	AOT 5	31882
51949	AOT 10	27305
51949	AOT15	23094
51949	AOT 20	19165
51949	AOT 25	15694
51949	AOT 30	12608
51949	AOT 40	7618
51949	AOT 50	3994

Values of AOTX in Table 2 were presented in a graphical form as shown in Figure 3. In Figure 3, concentrations of ozone that contribute to AOTX values were shown from 1st April 2004 to 31st June 2004.

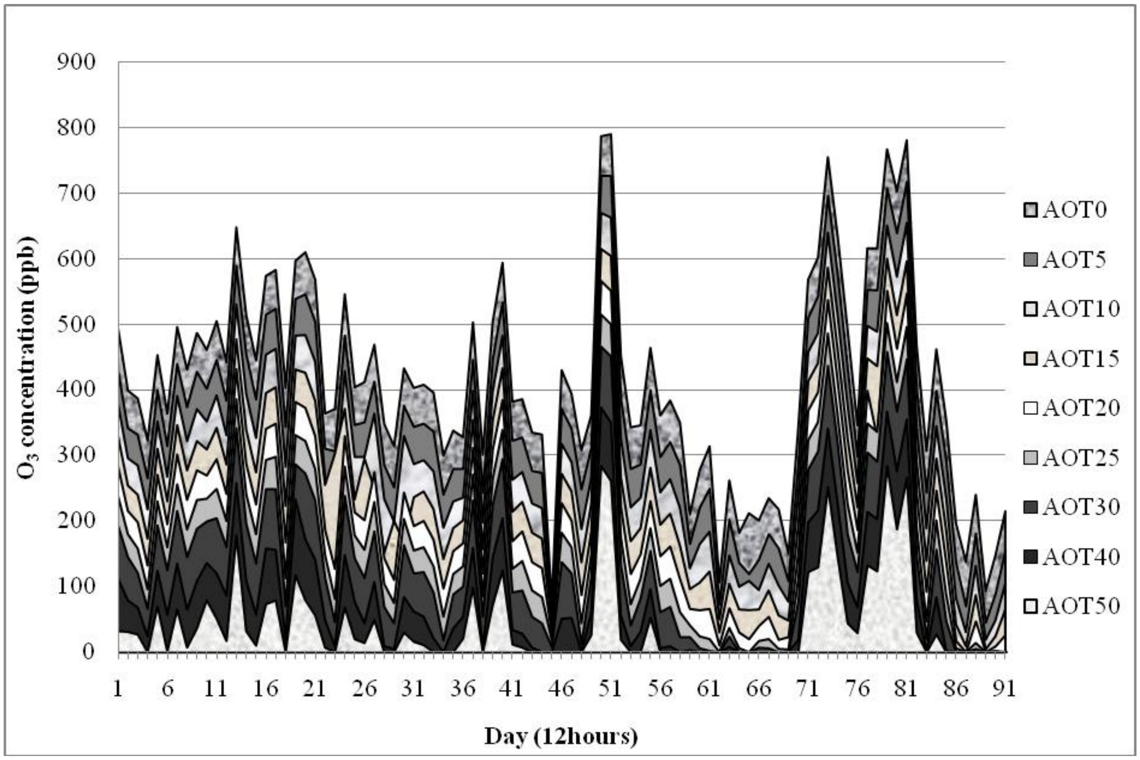

Figure 3: Contributions of ozone concentration to AOT0, AOT5, AOT10, AOT15, AOT20, AOT30, AOT40, and AOT50 for Kedah, Malaysia from April to June, 2004

According to Figure 3, there were two obvious periods, whereby the ozone concentrations were seen to lift up AOTX values. First period was from day 50 to 52 and second period was day 70 to 85. Day 50 to 52 in Figure 3 was equivalent to May 20 to May 22 in 2004 and day 70 to 85 was in June 19 to 24 in year 2004. From the meteorological study, south –west monsoon start from middle of May or early June. Therefore, during this season, most of area in Kedah faced drier and hotter atmosphere with less rainfall. Felzer et al. [15] an Ghazali et al. [16] pointed out that the ozone production occurs during times of high temperature and solar radiation, such as during the stagnant high pressure systems in summer.

3.3 Crops (Oryza Sativa) Reduction

According to the European benchmark, for AOT40 values more than 3000 ppb, there is a 5% of yield loss occurred [14]. As Malaysia does not has its own benchmark to estimate the loss due to ozone concentration in the atmosphere, result shows in Table 3 was adopted from the European benchmark in order to calculate the potential rice (*Oryza sativa)*loss in Kedah, Malaysia.

Table 3 shows the estimation of rice (*Oryza sativa)* loss due to the ozone exposure according to the European benchmark for year 2004.

Table 3: Paddy yield in Kedah for year 2004

District	Plantation area (hectare)	Actual yield (tonne/hectare)	Actual yield (tonne)	Potential yield (tonne/hectare)	Potential Yield (tonne/hectare)	Loss (tonne)	Loss (tonne/ hectare)
Bandar Baharu	864	3.649	3152.74	3310.37	3.83	157.64	0.18
Kota Setar	3328	3.131	10419.97	10940.97	3.29	521	0.16
Kuala Muda	7110	1.897	13487.67	14162.05	1.99	674.38	0.09
Kubang Pasu	3560	4.603	16386.68	17206.01	4.83	819.33	0.23
Kulim	905	3.754	3397.37	3567.24	3.94	169.87	0.19
Langkawi	0	-	-	-	-	-	-
Padang Terap	3534	3.179	11234.59	11796.32	3.34	561.73	0.16
Pendang	4022	4.348	17487.66	18362.04	4.57	874.38	0.22
Sik	465	2.674	1243.41	1305.58	2.81	62.17	0.13
Yan	1150	2.362	2716.3	2852.12	2.48	135.82	0.12
Total	**25877**	**31.95**	**81733.03**	**85819.68**	**33.54**	**4086.65**	**1.6**

From Table 3, the actual yield obtained was 81733.03 tonnes. However, the exposure of paddy to ozone and the excellence of the AOT40 values during this period had led to paddy yield loss of 4086.65 tonnes. From the calculation, 33.54 tonne per hectare of the potential paddy yield should be obtained. This result suggests that there is 1.60 tonnes per hectare of paddy yield loss occurred.

4. CONCLUSIONS

European benchmark has stated that 5% reduction in yield for both crops will be expected to occur if the accumulated of ozone concentration within that duration is above 3000ppb.h. However, as most of the studies done on AOT40 were performed in Europe, Mediterranean, and America regions, this index does not consider the climatic different in other regions that might affect the ozone sensitivity due to the different rates of plant growth or different cut-off concentration (Accumulated exposure Over a Threshold of X ppb (AOTX)). Due to the limitation of data in current situation for Malaysia climate, AOTX response to crops in Kedah, Malaysia region cannot be done very well. Therefore, the most critical AOT indices due to crops reduction that suitable under Malaysia climate are still under investigation. However, from calculation done on paddy yield loss in Kedah according to the European benchmark, the highest AOT40 values achieved was 7618 ppb, which occurred in April to June 2004. This result suggests that there was 1.60 tonnes per hectaree of paddy yield loss had occurred.

5. ACKNOWLEDGEMENTS

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