Relationship between AOTX Indices and Crops Response towards Ozone Concentration in Malaysia

Nurul Izma Mohammed
Nor Azam Ramli*
Ahmad Shukri Yahya
Nurul Adyani Ghazali
Ahmad Zia Ul-Saufie
School of Civil Engineering, Engineering Campus
Universiti Sains Malaysia, 14300 Nibong Tebal
Penang, Malaysia
E-mail: ceazam@eng.usm.my*, Phone No.: + (60)4-5996227*

Abstract

The purpose of this study was to analyze the contributions of ozone to different AOT indices, which were AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 in Kedah, Malaysia. Besides that, this study was aimed to test the response of crops towards these different AOT indices, under the Malaysia climate. Environmental parameter that was employed in the study was the ozone concentration. This data was analyzed from 7a.m to 7p.m every day from year 2004 to 2006. From this study, AOT0 was considered to be a control index. The present results demonstrated that AOT50 gave the highest response on crops under the Malaysia climate. Therefore, this study suggests that AOT50 of 1777.5 ppb.h are the most critical AOTX indices towards the crops response to ozone in Malaysia. This result however, was different from AOT40 of 3000 ppb.h, which is recommended for crops in European countries.

Keywords: *AOT40, AOT50, critical level, crops, Malaysia, ozone.*

1. Introduction

Ozone has long been known to affect the agricultural yield as it affects the crops characteristics (Heck et al., 1988). Therefore, in 1988 at Bad Harzburg, Germany, the critical levels to protect crops from the effect of ozone were set (Fuhrer et al., 1997). According to Bull (1991), the convention agreed to adopt the critical loads and the critical level concept for the evaluation of the adverse effects on crops by the environment pollutants. Critical level was defined as "the atmospheric concentration of pollutants in the atmosphere above which adverse effects on receptor, such as human beings, plants, ecosystem, or materials, may occur according to present knowledge" (UNECE, 1996; UNECE, 2007). Clearly, the critical level was set to ensure that all crops, which may be affected due to the ozone exposure, are protected. Critical levels based on the AOT40 approach play an important role in evaluating the ozone impacts on the vegetation (Fuhrer et al., 1997; Keller et al., 2007). The long term critical level of AOT40 of 3000 ppb.h for crops is used only to define the areas at risk, where the critical level is exceeded. Therefore, AOT40 is hoped to reduce the exceedance of the ozone level (Simpson et al., 2007). Sequence of the AOT40 as the critical level was as Table 1 follows.

Table 1: Sequence of AOT40 as the critical level (Fuhrer et al., 1997; Karlsson et al., 2004)

As AOT40 has also been considered by the World Health Organization (WHO) for the revised Air Quality Guideline for European country, this index however, has been used by other countries as their guideline as well. Nonetheless, 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 the different cut-off concentration (Accumulated exposure Over a Threshold of X ppb (AOTX)) such as 40 nmol mol $^{-1}$ in AOT40 (Karlsson et al., 2003).As ozone is a secondary pollutant, it is highly related to these atmospheric variables. In Malaysia, due to the lack of awareness regarding the effects of the ozone exposure towards vegetation, a few numbers of researchers have studied this issue. As to date, the air quality guideline for the ozone in response to the vegetation is still unavailable in Malaysia. The first aim of this study was to look at the contributions of the ozone to the nine different AOT indices, which were AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50. The second objective was to test the response of crops production towards these nine AOT indices, under the Malaysia climate in Kedah, Malaysia. Lastly, this study was aimed to suggest the new AOTX benchmark with its critical limit under the Malaysia climate.

2. Materials and Method

2.1 Study area and local meteorology

Kedah is located in the north of Peninsular Malaysia, covering an area of 9426km^2 and border to Thailand (Figure 1 a).

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 b).

Figure 1 (a, b): Map of Kedah, Malaysia (Kedah portal, 2011)

According to Malaysia Meteorological Services (MMS), Kedah is generally divided by the two monsoon seasons, which are the south-west monsoon and the north-east monsoon. The South-west monsoon usually starts in the later half of May or early June the end of September while the north-east monsoon starts on early November until March. During the 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. The monthly rainfall pattern shows that the two periods of the maximum rainfall is separated by the two periods of the minimum rainfall. The primary maximum generally occurred from October to November while the secondary maximum is normally occurred in 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).

Kedah, Malaysia is well known to experience high humidity. The mean relative humidity varies from as low as 72% to as high as 87%. The minimum relative humidity is normally found in the months of January and February. The maximum, however, is generally found in the month of November. The temperature in the study area is usually between 27 to 30 °C during the daytime and 22 to 24°C during the night time (Malaysian Meteorological Department, 2008). The population in this state was approximately 1.9 million in 2010 (Kedah portal, 2011). This region is deemed as the focal point of the paddy growth in Malaysia as it produces one third of Malaysia’s total rice production. Besides paddy, it also produces many other crops that contribute to the economic growth in the state, for instance, spinach, chinese kale, water spinach, cabbage, lettuce, and long bean.

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 on Sungai Petani, as this area is largely surrounded by agricultural area, compared to the other two stations. Secondary data of the ozone concentration from the Department of Environment (DoE), Malaysia was employed for the ozone contribution to the AOTX indices. The quality assured data of the ozone was provided by the DoE. The data are regularly subjected to standard quality control processes and quality assurance procedures by the DoE. The period of data was from year 2004 to 2006 and the data observed was 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 low ranges of ozone in the ambient air.

2.3. Analytical procedures

The first objective is to calculate the exposure indices, AOTX. AOTX is a cumulative exposure index, which is calculated during the light hours (7a.m to 7p.m) as the sum of the differences among the hourly concentration (in ppb) over a period of three months time and X ppb for each hour when the concentration exceeds X ppb (UNECE, 1999).

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

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 (Grunhage et al., 1999).

The second objective is to estimate the percentage of crops response towards the AOTX indices due to the ozone exposure from year 2004 to 2006 by using the secondary data, provided by the Department of Agricultural, Malaysia (DoA).

$$\text{Percentage of crops response (\%)} = \frac{AOTX_{(Y)}}{\Sigma Ozone\ \ concentration\ \ _{(y)}} \times Crops\ production \qquad (2)$$

Where, X is the index of AOT and y is the year of the collected data.

The response of crops towards AOTX indices was conducted by using Microsoft Office Excel 2007. The last objective is to suggest the new benchmark of AOTX indices with its critical limit in response to the crops under Malaysia climate. The new benchmark is depending on the results obtained from the second analysis. The highest AOTX acquired in response to the crops will be suggested as the benchmark.

The critical limit will be obtained from the median value of the AOTX from year 2004 to 2006.

3. Results and Discussion

The contribution of the ozone to nine different AOT indices, which are AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 in Kedah for 2004, 2005, and 2006
was shown in Table 2.

Table 2: Values of AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 in Kedah for 2004, 2005, and 2006.

In this study, AOT0 was considered to be the control index as many studies have reported that ozone has a lot of potential to give adverse impacts on plants (Pleijal et al., 1998). In Table 2, AOT50 gave the lowest value of the accumulated exposure of the ozone compared to the others. The value of AOT50 from July to September, 2004, January to March, 2005, and July to September, 2006 recorded as the highest accumulated exposure of ozone in each particular year while October to December in year 2004, 2005, and 2006 showed the lowest value of AOT50 compared to the other period. The same pattern goes to the value of the AOTX in these three years. Ozone concentrations in year 2005 were much higher than those in year 2004 and 2006. According to the meteorological condition, maximum rainfall in the study area starts from October to November every year. Besides that, the north-east monsoon that provides heavy rainfall to the study area begins in November. Rainfall cleans the atmosphere, thus, removes away the pollutants such as the nitrogen dioxides, the precursor of ozone. This phenomenon is clearly observed in the reduction of the ozone concentration during the raining period as reported by Pudasainee et al. (2006).This explains the low AOTX value on October to December for year 2004,2005, and 2006 (Table 2).

During the rainy season, the presence of UVB will lessen, the temperature will decline, and the humidity in the area will increase. This phenomenon will reduce the rate of the ozone transformation. Likewise, insufficient solar radiation and the washout of pollutants will result in the near absence of the photochemical ozone transformation (Lal et al., 2000). Therefore, formation of the 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 (Abdul-Wahab et al., 2005). Contributions of the ozone toward the nine different AOT indices from July to September in 2004 and 2006 were higher compared to other months (Table 2). This phenomenon was caused by the climate condition, where minimum rainfall usually occurs during this period. Moreover, when the humidity decreased and the temperature increased, this phenomenon will result in the augmentation of the ozone formation in the atmosphere. According to Ghazali et al., (2010), the formation of the ozone is heavily influenced by the sunlight and temperature. Besides that, 'high-ozone episode' can be generally attributed to a build up of air pollutants associated with stagnating meteorological conditions brought on by slow-moving high pressure systems (Luo et al., 2000). The relationship between the nine AOT indices, AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 and the response of crops towards the ozone concentration in Kedah, Malaysia for 2004 was shown in Figure 2(a), (b), (c), (d) .

Figure 2(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2004

From Figure 2(a), the highest percentage of the crops response towards the ozone exposure was the best with AOT0 index (control index) with 8.22 % in January to March, 2004. This percentage was followed by AOT5 with 8.20 % while AOT50 gave the least percentage with 5.11 %. AOT40 which was recommended for the crops in Europe gave the second least percentage with 6.42%. In Figure 2(b), AOT50 recorded the highest percentage of the crops response towards the ozone exposure with 13.44 % from April to June 2004, followed by AOT40 with 12.52 %. AOT0 (control index) which produced the highest percentage from January to March, 2004 however showed the smallest percentage of crops response towards the ozone exposure during these months with 9.27 %.

The percentage of the crops response towards the ozone exposure was highest with AOT50 index, followed by AOT40 by 0.55 % from July to September 2004 [Figure 2(c)]. The pattern of AOT indices during these months was almost similar with the previous months, April to June, 2004, where AOT0 (control index) was the least index in response to the crops with 8.47 %. AOT0 (control index) recorded the utmost percentage in the crops response towards the ozone exposure with 6.61 % in Figure 2(d). However, this value is considered small as compared to the other months throughout 2004. AOT40 which was recommended by European countries as the critical index for the crops gave the second least percentage of the crops response towards ozone with 1.84% followed by AOT50 index with only 1.43 %. This value was the smallest percentage in crops reduction in 2004.

The relationship between the nine AOT indices, AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 and the response of the crops towards the ozone concentration in Kedah, Malaysia in 2005 was shown in Figure 3(a), (b), (c), (d) .

Figure 3(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2005

From Figure 3(a), the crops response towards the ozone exposure was amplified tremendously towards AOT50 from January to March, 2005 with 14.7 % of the crops response recorded. This percentage followed by AOT40 with 14.36 % while AOT5 was the least percentage with 8.22 %. In Figure 3(b), AOT50 recorded the highest percentage in the crops response with 12.65 % from April to June 2005, followed by AOT40 with 12.12 %. AOT5 exhibited the smallest percentage during these months with 9.27 %. The percentage of the crops response towards the ozone concentration was the highest with AOT50 index with 8.65 %, followed by AOT5 [Figure 3(d)]. The difference between these two indices was 0.18 % in July to September 2005. AOT40 recorded 8.28 % of the crops response towards ozone exposure, which was slightly behind AOT5. AOT15 and AOT25 were the least index in response to crops with 7.94 % each.

AOT0 (control index) recorded the greatest percentage in the crops response towards the ozone exposure with 6.68 % in Figure 3(d). However, this value is small compared to the other months throughout the year of 2005. AOT40 which was recommended by European countries as the critical index for the crops gave the second least percentage of the crops response towards ozone with 1.96 %, followed by AOT50 index in October to December 2005 recorded that the response of the crops towards the ozone exposure was only 1.84 %. This value was the smallest percentage in the crops reduction in 2005. The relationship between the nine AOT indices, AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 and the response of crops towards ozone concentration in Kedah, Malaysia in 2006 was shown in Figure 4(a), (b), (c), (d) .

Figure 4(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2006

From Figure 4(a), the highest percentage of the crops response towards the ozone exposure was the best with AOT0 (control index) and AOT5 index with 10.41 % in January to March, 2006. This percentage followed by AOT10 with 10.38 % while AOT50 was the least percentage with 8.10 %. AOT40 which was recommended for the crops in Europe gave the second least percentage with 9.89 %.In Figure 4(b), AOT0 (control index) recorded the highest percentage in crops response with 10.05 % from April to June 2006, followed by AOT5 with 10.02 %. AOT40 which was recommended by European countries as the critical index for the crops gave the second least percentage of the crops response towards ozone with 8.34 % followed by AOT50 which showed the smallest percentage of the crops response during these months with 7.87 %. The percentage of crops reduction was the highest with AOT50 index with 14.73 %, followed by AOT40 with 12.96 % in July to September 2006 [Figure 4(c)]. AOT0 (control index) was the least index in response to the crops reduction with 9.91 %.

AOT0 (control index) recorded the greatest percentage in the crops response towards the ozone with 9.28 % in Figure 4(d). However, this value is small compared to the other months throughout 2006. AOT40 and AOT50 indices in October to December, 2006 recorded the reduction in crops response with only 4.91 % and 4.03 % respectively. This value was the smallest percentage in the crops reduction in 2006. According to Figure 2(a, b, c, d) to Figure 4(a, b, c, d), the results showed that AOT0 (control index) and AOT50 indices were the most dominant index in these three years in impacting the crops production. This result however shows that none of these months recorded that AOT40 index was the most critical index in response to the crops reduction, eventhough it is recommended as the critical level for crops in Europe. In the 3 years analysed, it is apparent that crops response towards AOT0 (control index) is highest in the months of January to March. During this time Kedah's meteorogically governed by the North-east monsoon those results in heavy downfall. Throughout the monsoon period, the sky is generally cloudy. This condition leads to the decreasing of the solar insulation thus reducing the photochemical processes (Reddy et al., 2010).

During the rainy season some of the pollutants are washed out. Therefore, these two factors could cause low levels of ozone during monsoon period (Shan et al., 2008; Jo et al., 2000). However, higher humidity and mild temperature can increase stomatal conductance and thus ozone uptake by the leaves of wheat, which results in more yield loss (Huixiang et al., 2005). This also explains the data figures for the month of October to November. In between these 2 periods of heavy downfall, Kedah experience the South-West monsoon which brings with it higher temperature and less rainfall. In these months (April to September), the highest crops response towards AOTX indices was AOT50. During this time, the ambient air becomes unstable and rises due to heating of the earth surface by solar radiation. According to Naja and Lal (2002), favourable conditions for photochemical ozone production are high temperature, high intensity of solar radiation, and sufficiently high concentrations of nitrogen oxides.

Therefore, the dispersion of air pollutants accelerates and the mixing of low ozone amount air in the surface layer with high ozone amount air in the upper layer also gets faster (Lal et al., 2000; Shan et al., 2008). The differences of crops response towards AOT0 (control index) and AOT50 are highly related to the meteorological parameters such as temperature, cloudiness, sunlight, and wind speeds (Racherla and Adams, 2007). Therefore, changes in these meteorological parameters due to climate change will necessarily affect the response of crops towards AOTX indices. Besides that, high concentrations of precursor gases, which are caused by local emissions or transport from the regional sources and the Stratosphere–Troposphere Exchange (STE), will as well, caused the same affect (Reddy et al., 2008a). In the European countries, the AOT40 critical levels is anticipated to cause a 5% crops reduction for agricultural crops, which 3000 ppb.h for daylight hours during a three – month period (UNECE, 1996).

Therefore, as AOT0 and AOT50 have the most impact on the crops response under Malaysia climate, the new critical levels for both AOT 0 and 50 were being scrutinized. However, as AOT0 is a control index, only AOT50 was selected as the new critical level for ozone in Malaysia. This calculation was done according to the European standard, in which the cumulative concentration of the critical index is anticipated to cause a minimum of 5 % crops reduction, at least. Subsequent to the several studies done, the median value of the AOT50 from 2004 until 2006 indicated a similar percentage of the crops reductions with the AOT40, which is currently being utilized in the European countries. The median value for the AOT50 from 2004 until 2006 was 1777.5 ppb.h. The percentage of the crops reduction using median value of AOT50 from 2004 to 2006 was shown in Table 3.

Table 3: Percentage of the crops reduction using median value of AOT50 from 2004 to 2006.

The crop response percentage for AOT40 and AOT50 was demonstrated in Table 3. According to the European standard, for every 3000 ppb.h of AOT40, a minimum of 5 % reduction of the crops yield will occur. Hence, the percentage of the crop reduction calculation for the AOT50 was carried out according to the corresponding guideline, yet, employing the proposed critical level; the median values of the AOT50 from 2004 to 2006 and new percentage of reduction, 6%. Based on Table 3, the percentages difference among the AOT40 and AOT50 was very minuscule with the difference between 0.32 to 1.62 %. Thus, the new value of the critical level for AOT50 was considered to be acceptable. In spite of this, further study ought to be completed in order to attain the most accurate values for this AOT index. Therefore, this study suggests that the AOT50 of 1777.5 ppb.h are the new critical levels to estimate the potential ozone impacts on the crops under Malaysia climate.

4. Conclusion

The present results demonstrate that the accumulated ozone exposure of 0 and 50 nmol mol $^{-1}$ gave the major impact on the crops production under the Malaysia climate. The differences of crops response towards AOT 0 (control index) and AOT 50 are related to the meteorological condition in Malaysia. The relationship of AOT 0 and AOT 50 with the crops response towards the ozone exposure under the Malaysia climate were much different from 40 nmol mol $^{-1}$ as threshold level (AOT40) that is recommended for crops in Europe. Since AOT0 is a control index, only AOT50 was selected as the new critical level for ozone in Malaysia Therefore, this study suggests that the AOT50 of 1777.5 ppb.h is the new critical levels to estimate the potential ozone impacts on the crops under Malaysia climate. However, further study ought to be completed in order to attain the most accurate values for this AOT index.

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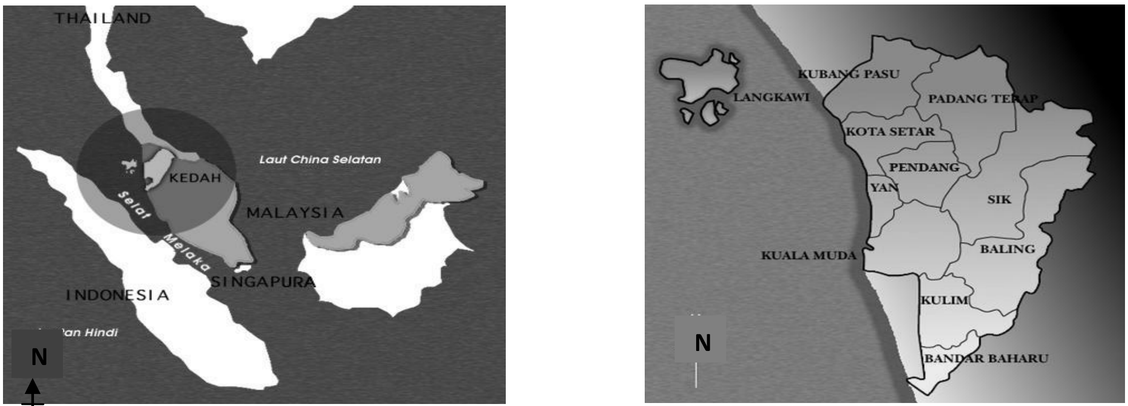
Appendices

Table 1: Sequence of AOT40 as the critical level (Fuhrer et al., 1997; Karlsson et al., 2004)

Year	Vanue	Output
1988	Bad Harzburg, Germany	Critical levels for ozone were initially introduced. During this period, the critical levels for ozone were expressed as a seasonal concentration
1992	Egham, United Kingdom	Proposed to replace the seasonal concentration with the cumulative exposure over a threshold concentration for a given time length
1993	Bern, Switzerland	The threshold concentration concept was adopted and it was set at 40 ppb, where it resulted an AOT40 term (Accumulated exposure over a threshold of 40 ppb).
1996	Kuopio, Finland	The attendees of the workshop were finally agreed on the usage of AOT40 index as a critical level for crops, forest tree and semi-vegetation in Europe
2002	Gothenburg, Sweden	AOT40 index has been re-analysed and expanded to include additional AOT indices such as AOT 20, AOT 30, and AOT 50



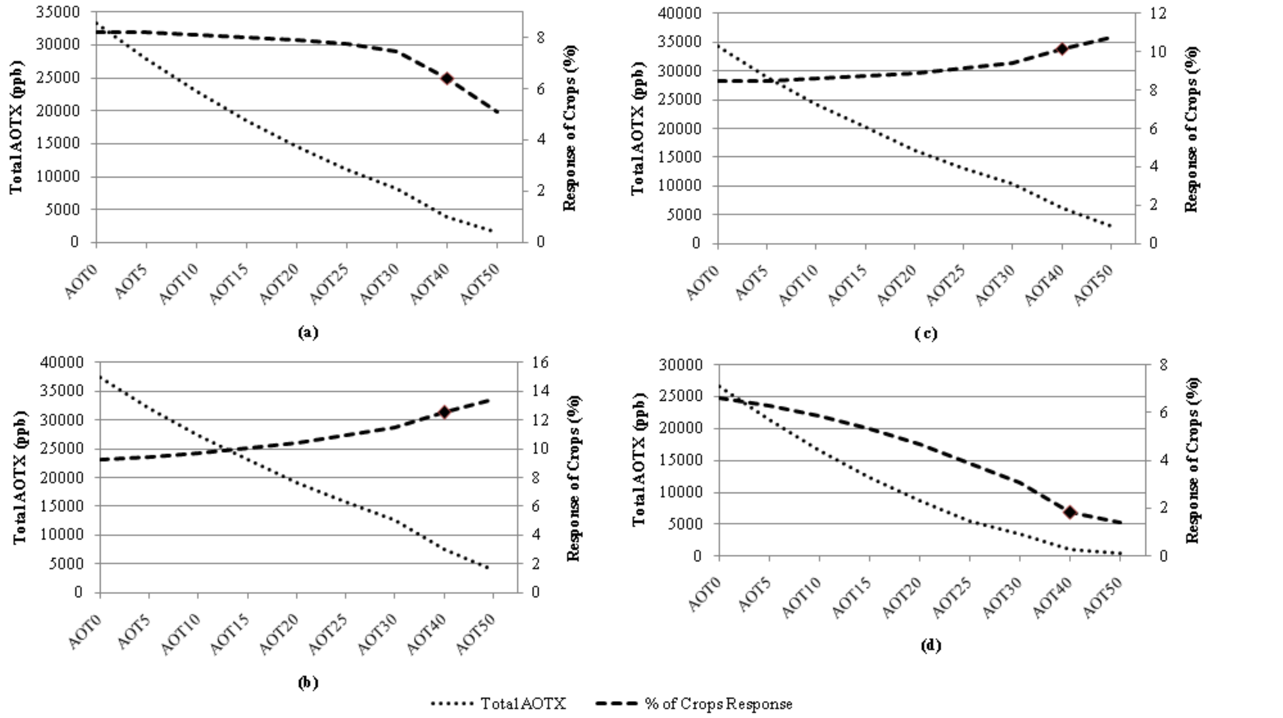
(a) (b)

Figure 1 (a, b): Map of Kedah, Malaysia (Kedah portal, 2011)

Table 2: Values of AOT0, AOT5, AOT10, AOT15, AOT20, AOT25, AOT30, AOT40, and AOT50 in Kedah for year 2004, 2005, and 2006.

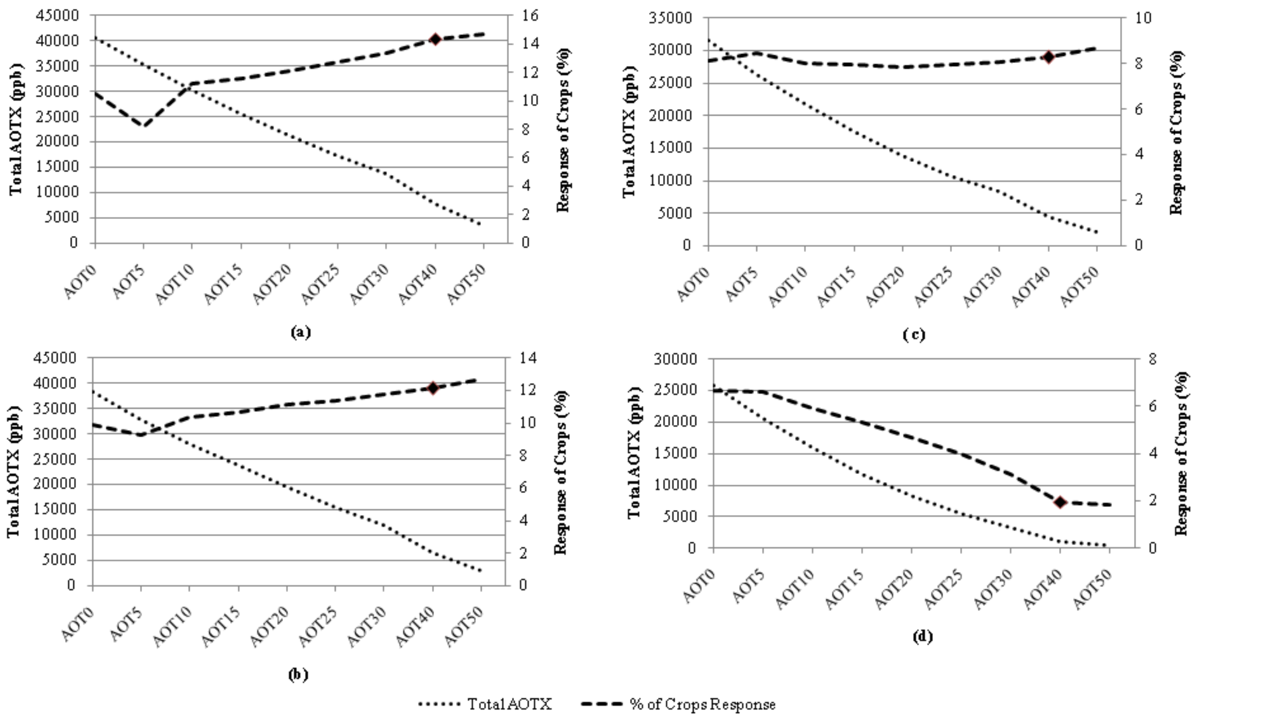
Year	Month	*AOT0	AOT5	AOT10	AOT15	AOT20	AOT25	AOT30	AOT40	AOT50
2004	January to March	**33189**	27837	22997	18467	14565	11119	8179	3908	1518
	April to June	**37408**	32037	27410	23159	19191	15694	12608	7618	3994
	July to September	**34199**	28845	24277	20223	16278	13077	10373	6185	3184
	October to December	**26686**	21403	16641	12338	8613	5578	3382	1122	425
2005	January to March	**40613**	35285	30283	25630	21293	17317	13757	7797	3460
	April to June	**38199**	32884	28054	23644	19519	15408	12094	6580	2979
	July to September	**31581**	26285	21701	17556	13806	10782	8307	4497	2037
	October to December	**25900**	20595	15974	11820	8263	5401	3208	1067	433
2006	January to March	**31689**	26450	21728	17456	13566	10264	7648	3862	1426
	April to June	**30592**	25451	20937	16747	12943	9669	6955	3256	1386
	July to September	**30161**	25325	21034	17134	13698	10895	8607	5060	2595
	October to December	**28243**	23148	18613	14441	10708	7525	5002	1915	710

*AOT0 is the control index of AOTX



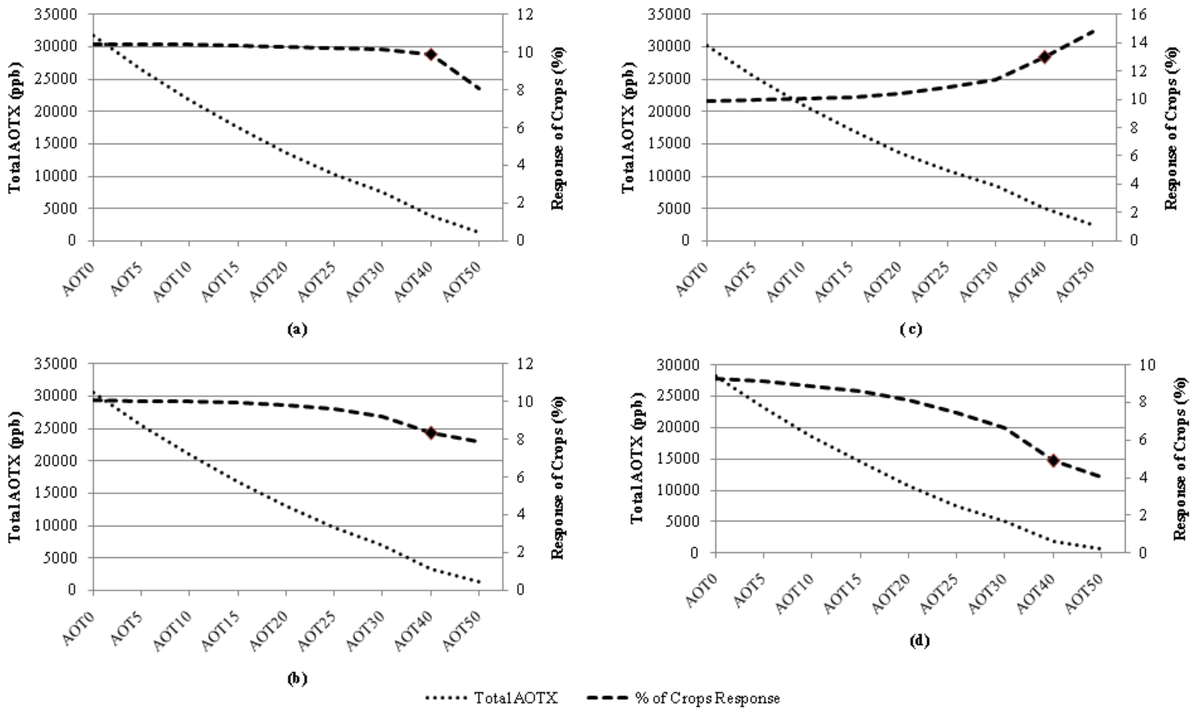
* ◆ AOT40 is the AOTX index which was recommended for crops in Europe

Figure 2(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2004



* ◆ AOT40 is the AOTX index which was recommended for crops in Europe

Figure 3(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2005



* ◆ AOT40 is the AOTX index which was recommended for crops in Europe

Figure 4(a): January to March, (b): April to June, (c): July to September, (d): October to December: Relationship between AOTX and crops response for Kedah in 2006

Table 3: Percentage of the crops reduction using median value of AOT50 from 2004 to 2006.

Year	Month	*AOT40	% of Reduction	AOT50	% of Reduction
2004	January to March	3908	6.51	1518	5.12
	April to June	7618	12.70	3994	13.48
	July to September	6185	10.31	3184	10.75
	October to December	1122	1.87	425	1.43
2005	January to March	7797	13.00	3460	11.68
	April to June	6580	10.97	2979	10.06
	July to September	4497	7.50	2037	6.88
	October to December	1067	1.78	433	1.46
2006	January to March	3862	6.44	1426	4.81
	April to June	3256	5.43	1386	4.68
	July to September	5060	8.43	2595	8.76
	October to December	1915	3.19	710	2.40

* AOT40 is the AOTX index which was recommended for crops in Europe, where AOT40 values more than 3000 ppb, there is a 5% of yield loss occurred