The Impact of Ozone Concentration on Crops

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Abstract

This study analyzes the data from the Environment Protection Administration's air monitoring stations, using the year 2016 as the research period, to observe and summarize the environmental conditions suitable for crop growth.

This research compared the ozone concentration by region, altitude and season. Hopefully by doing so, the most suitable environment for crops to grow can be found.

For futher use, this research method can be optimize to a better and more simple way to check if a place is ideal for cultivating certain types of crops.

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1 Introduction

1.1 Study Background

Ground-level ozone (O_3), a potent phytotoxic air pollutant, exerts deleterious impacts on agricultural productivity and quality, as evidenced by scholarly research (Ainsworth, 2017; Tai et al., 2014). The noxious effects of ozone on plants encompass multifaceted detriments, including the disruption of photosynthetic processes, curtailment of gas exchange mechanisms, initiation of premature leaf senescence, and impeded growth of both natural vegetation and cultivated crops. Ingressing through stomatal apertures and permeating the cellular matrix, ozone may engender reactions within plant tissues, inciting intracellular oxidation and generating endogenous reactive oxygen species. Escalation of these oxidative species beyond tolerable thresholds induces irreversible impairments, notably manifesting as chlorotic and necrotic manifestations, thereby diminishing both the quantitative and qualitative aspects of crop yields (Chaudhary and Rathore, 2021; You and Chan, 2015).

Given the pivotal role assumed by plants in the regulation of ecological equilibrium, the injurious repercussions imposed by ozone-induced plant afflictions carry the potential to expedite environmental deterioration, thereby culminating in far-reaching ramifications for human well-being.

In Taiwan, ozone, in conjunction with fine particulate matter, emerges as a foremost atmospheric pollutant, routinely giving rise to elevated concentrations within the air quality index, thereby resulting in conditions detrimental to human health. (Lee et al., 2019; Tsai and Lin, 2021). Past studies on ozone in Taiwan have mainly focused on its impact on human health, while there is insufficient data and research on the effects of ozone on crop yields. Therefore, this study applied numerical simulations of ozone along with crop cultivation to analyze the optimal environmental conditions and seasons for plant growth, aiming to improve the efficiency of crop cultivation in Taiwan.

To further monitor, quantify, and understand the mechanisms of ozone damage to plants, Prof. Chen's group from the Department of Atmospheric Sciences and International Degree Program in Climate Change and Sustainable Development National Taiwan University built a brand-new greenhouse. In this experiment, our research team planted tomatoes, soybeans, spinach, and sweet potato leaves as bioindicators of the ecological impacts of air pollution.

1.2 Expected Achievements

In order to observe and generalize the feature of ozone concentration, this research used Microsoft Excel to illustrate different kinds of graphs, which made the target compared items clear. Line charts, box plots, and heat maps allow clear observations from this study:

1. Ozone concentration is higher in high-altitude areas and lower in low-altitude areas.
2. Ozone concentration is higher in outlying islands compared to the main island.
3. Ozone concentration is higher in spring and fall, especially in late spring, while in summer, regardless of the location in Taiwan, ozone concentration is significantly lower than in other seasons.

For this study, me and other interns in the same laboratory planted soybeans, sweet potato leaves, spinach, and tomatoes, hoping to observe the impact of ozone concentration on these crops by controlling other factors in the greenhouse. The selection of these crops is because some limited studies in Taiwan have shown that crops like sweet potatoes, spinach, and rice seedlings are susceptible to high ozone levels (e.g., Sun, 1994; Lin et al., 2001). On the other hand, this research used the observational data to analyze the most suitable regions and seasons for the growth of these crops. This research methodology can be applied to future crop cultivation, selecting the most suitable growing environment and season for various crops to enhance agricultural efficiency in Taiwan.

2 Methods

2.1 Observational data

The Ministry of Environmental's air quality monitoring network collects air quality data from various locations across the entire Taiwan, including ozone concentration data. Through this monitoring network, it is simple to inquire about ozone concentrations at nationally designated monitoring stations established by the Environmental Protection Administration, as well as at other individual monitoring stations. This includes both hourly concentration values and moving averages. Furthermore, the monitoring network also offers website integration capabilities, allowing for a deeper understanding of the air quality conditions in different regions of Taiwan.

2.2 AOT_{40} and Relative Yield

The AOT_{40} metric represents the prevailing European protocol utilized for the evaluation of ozone (O_3) hazards concerning vegetation. This metric encompasses the aggregate of hourly O_3 concentrations (expressed in units of parts per million multiplied by hours, i.e., ppm·hour) occurring throughout daylight periods wherein the O_3 concentration surpasses a designated 40 parts per billion (ppb) threshold, expressed as the following.

$$AOT_{40} = \sum_{i=1}^{n} max\left([O_3]_i - 40, 0\right)$$

where i is the number of hours, and $[O_3]$ is is in ppb. Additionally, this metric accounts for instances when solar radiation levels exceed 50 watts per square meter (W/m^2) during the active growth phases of plants (LRTAP Convention, 2010; Mills et al., 2007).

Relative yield (RY) is the proportion of crop yield when affected by O_3-induced harm in comparison to yield without any impact from O_3, expressed as:

$$RY_X = a(X - c) + b$$

where X is AOT_{40} for the studied crops, and a, b, and c are response coefficient obtained from laboratory experiments. In order to ascertain the dispersion pattern of the relative yield (RY, %) concerning the total O_3 exposure and stomatal flux, species-specific correlations RY measurements (AOT_{40}) were employed. This approach enabled us to quantify the influence of O_3 on agricultural yield, as outlined above.

3 Results

3.1 Ozone concentration compared by region

This study aims to determine the ozone concentration levels in different regions of Taiwan. To achieve this goal, four air quality monitoring stations were selected in the northern, central, southern, and eastern parts of Taiwan for observation. Since the study seeks to identify the most suitable environment for crop growth, and urban areas have fewer crops, all four selected air quality monitoring stations are located in rural areas. They are Fuxing in Taoyuan from northern Taiwan, Erlin in Changhua from central Taiwan, Renwu in Kaohsiung from southern Taiwan, and Guanshan in Taitung from eastern Taiwan.

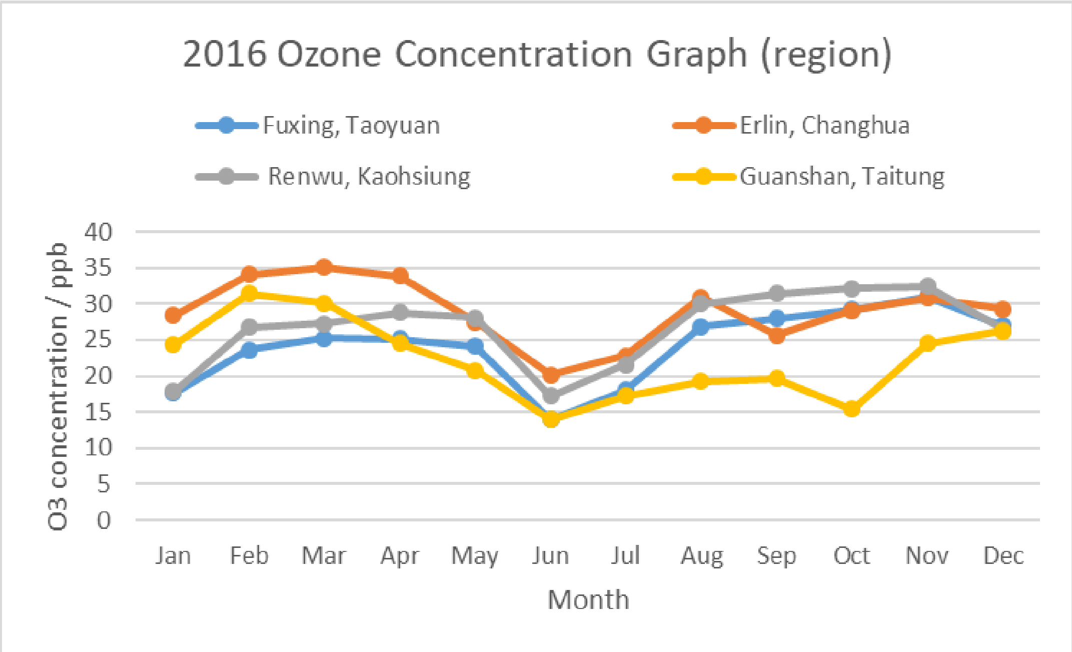

Figure 1. Line Chart of 2016 Ozone Concentration (region)

Using Microsoft Excel, line graphs were drawn to clearly observe the ozone concentration levels. It was observed that Erlin in Changhua and Renwu in Kaohsiung had higher ozone concentrations compared to the other regions, while Guanshan in Taitung had lower average ozone concentrations than the other three regions.

3.2 Ozone Concentration compared by altitude

Due to the hot summers in Taiwan, many crops are moved to higher-altitude mountainous areas for cultivation in late spring or summer, such as spinach and tomatoes. Therefore, this study compares the ozone concentrations between higher-altitude mountainous regions and lowland areas to observe whether mountainous regions are suitable as cool retreats for ozone-sensitive crops.

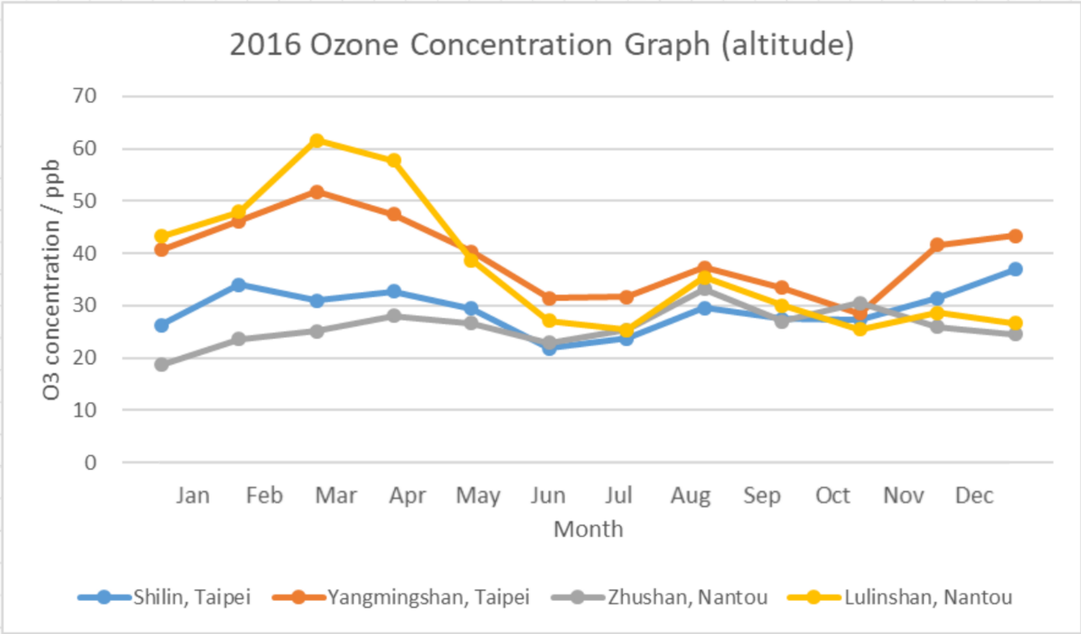

Figure 2. Line Chart of 2016 Ozone Concentration (altitude)

This study selected Yangming in Taipei and Lulinshan in Nantou as high-altitude target air quality monitoring stations, while Shilin in Taipei and Zhushan in Nantou were chosen as lowland target stations. Line graphs plotted using Microsoft Excel revealed that the ozone concentration in Taiwan's high-altitude regions is significantly higher than in the lowland areas, especially in the central region. From this, it can be inferred that the Central Mountain Range region is not the optimal location for crops to escape from the intense heat.

3.3 Ozone Concentration compared by season

This study aims to understand the ozone concentration levels in Taiwan throughout the four seasons, in order to provide references for agricultural crop planting periods. For ozone-sensitive crops, recommendations will be given for the suitable planting seasons or the use of greenhouse cultivation. To accomplish this, line graphs was plotted by Microsoft Excel, comparing the ozone concentrations from all air quality monitoring stations across Taiwan, to observe the variations in ozone levels during different seasons.

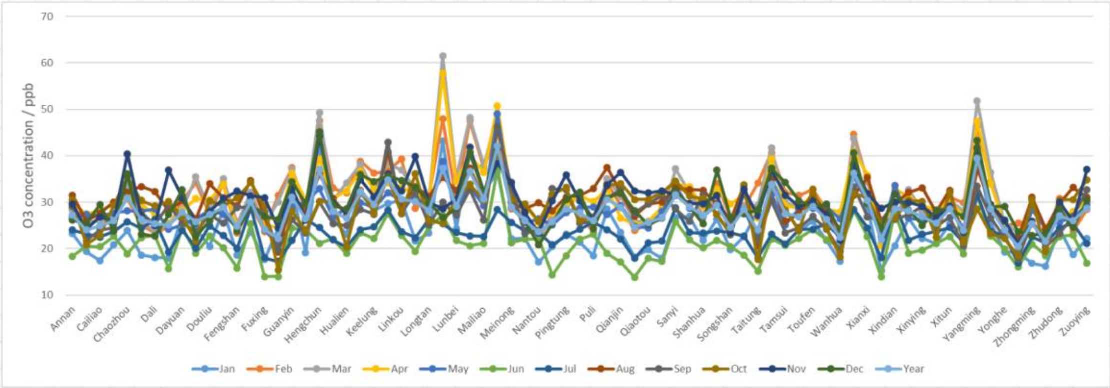

Figure 3. Line Chart of 2016 Ozone Concentration (all air quality monitoring stations)

Based on this line graph, it can be observed that, in general, the ozone concentration is lowest in June and July, while it reaches its highest levels from February to April. Under conditions where other factors remain constant, farmers can arrange the planting time for ozone-sensitive crops, such as spinach and tomatoes, they can either plant the crops during summer or consider using greenhouse cultivation. For crops that are less affected by ozone concentration, they can be planted in the spring, such as sweet potato leaves.

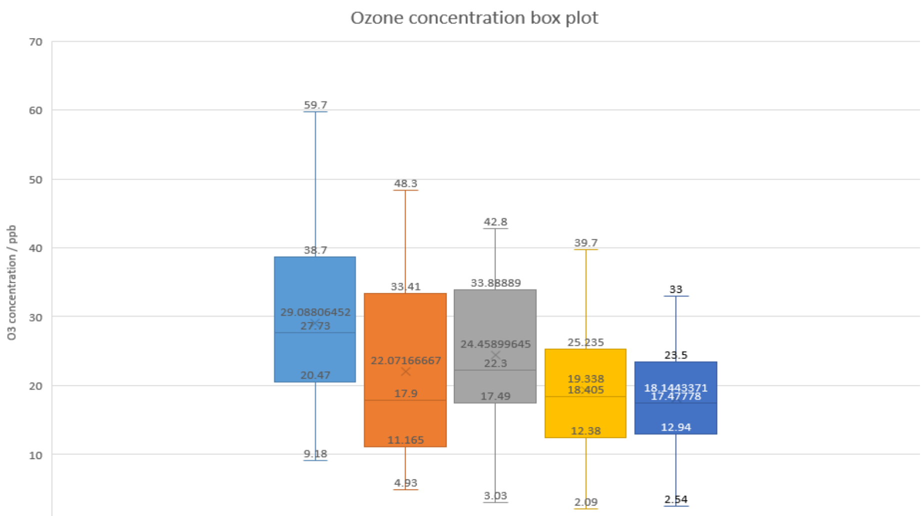

Figure 4. Box plot of Zhushan (August to December, 2016)

3.4 AOT_{40} Calculation and Relative Yield Estimation

After observing data from air quality monitoring stations, this study utilized the AOT_{40} model to analyze the response of crops to ozone concentration. Given that tomatoes are highly sensitive to ozone, this research conducted experiments using tomatoes as a case study. In Taiwan, the tomato growing seasons are divided into two periods: spring-summer and fall-winter. Ozone concentration is higher during the fall-winter season. The central region is a major production area for tomatoes. Therefore, this research focused on the fall-winter growing season, which is August to December, in central Taiwan to analyze AOT_{40}.

Season	AOT40	RY
Fall	2902.35	-23.039705
Spring	2563.84	-20.230072

In order to ascertain the dispersion pattern of the relative yield (RY, %) concerning the total O_3 exposure and stomatal flux, species-specific correlations between RY and AOT40 measurements were adopted. This approach enabled us to quantify the influence of O_3 on agricultural yield.

The estimated amount of relative yield of tomato at different seasons during the year are as follow: approximately -23.0397 in fall (mid-August ~ mid-November) and -20.2301 in spring (mid-January ~ mid-April). As the result shows, fall had better relative yield than in spring.

4 Conclusions

4.1 Expected Outcome

The expected outcomes of this study are as follows:

1. Plant spinach and closely observe the impact of ozone concentration on it in a greenhouse, with the aim of obtaining ozone sensitivity-related parameters for the growth model.
2. Analyze the data from air quality monitoring stations all over Taiwan and present the results clearly through charts, in order to understand the variations in ozone concentration under different comparative conditions.

4.2 Evaluation

1. The original intention was to cultivate spinach for the purpose of observing and calculating AOT_{40}. However, due to the fact that this study was conducted during the summer, while spinach's growing season occurs in winter, the efficiency of spinach growth was compromised. Consequently, in this study, a substitution was made, and similarly ozone-sensitive tomatoes were employed as an alternative crop.
2. Using data from air quality monitoring stations, the aim was to create charts and analyze where in Taiwan and during which seasons the conditions are conducive for successful crop growth. However, due to delays in greenhouse construction progress, the observation and calculation of the AOT_{40} variable specific to the Taiwan region could not be successfully completed, which is regrettable. In the future, as the experimental timeline extends, it will be possible to continue the numerical computations for this unsuccessful aspect of the research.
3. Relative yield is evaluated for different growth seasons. The results followed AOT_{40} variable specific. Therefore, the accurate amount of relative yield would be countable as long as those variables are known.

4.3 Future Work

This study can contribute to various aspects of future work and society:

1. Optimization of Crop Cultivation and Harvest: Researching the sensitivity of crops to ozone concentration can assist farmers in selecting cultivation locations, seasons, and plant varieties more accurately, thereby maximizing crop growth efficiency and yield. This will contribute to improving food production and food security.

2. Environmental Monitoring and Management: The research findings can be applied to environmental monitoring systems to assess ozone concentrations in different regions and evaluate their impact on surrounding ecosystems and crops. This aids in more effective control and reduction of environmental pollution, preserving ecological balance.
3. Protection of Human Health: By determining the sensitivity of crops to ozone, a better understanding of whether crops are affected by pollutants can be gained. If plants cannot grow healthily and fulfill their natural functions, the entire ecosystem, including human health, is at risk. Hence, this research helps ensure that the air and environment remain free from harmful substances, thus safeguarding public health.
4. Extension of Research Methodology: This simple and executable methodology can be expanded to other research fields, further exploring the effects of different factors on crop growth and health. This approach holds potential application value in fields such as agriculture and environmental science.

In conclusion, this study may provide significant potential benefit to increasing crop yields, ensuring food quality, and even safeguarding the environment. Simultaneously, its straightforward and practical approach may also offer new inspiration and directions for related research endeavors.

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