Newsletter

Plants and Pollution

ENVIS-NBRI

Rise in Tropospheric Ozone Harms Crop Yield

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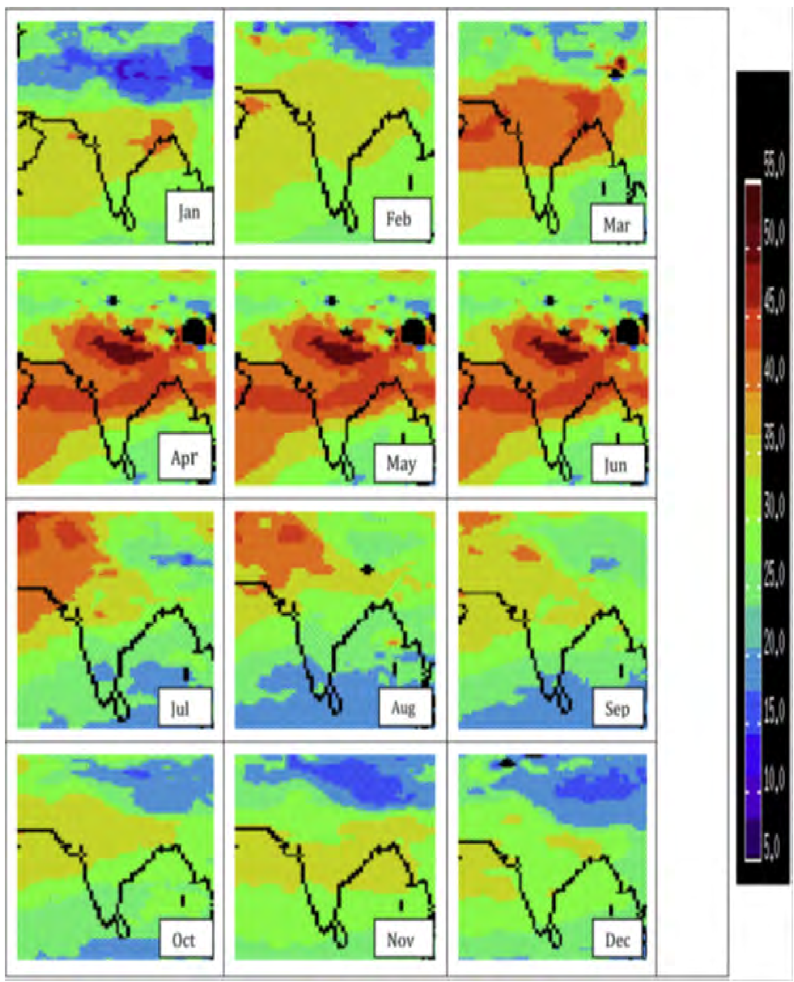
CSIR - National Botanical Research Institute, Lucknow

What is ground-level ozone and why does it matter?

Ozone (O_3) is a natural constituent of the atmosphere and is present in the stratosphere and troposphere. In the stratosphere, O_3 is produced following the photolysis of molecular oxygen. At this level 'ozone layer' acts as a protective layer filtering out dangerous UV radiation from the sun. Ozone present throughout the troposphere and at the Earth's surface is known as (ground-level O_3) or bad ozone. In the troposphere, O_3 is a green house gas. It is a secondary pollutant generated through sunlight driven chemical reactions between NO_x (nitrogen oxide gases) and VOC (volatile organic compound) including CH_4, CO and many other more complex compounds. Troposphere contributes only 10% of the atmospheric column. Along with detrimental health effects Ozone impairs plant metabolism, leading to yield reductions in agricultural crops. It has therefore emerged as a global food security problem. The global background level of O_3 has more than doubled since the industrial revolution and its peak value regularly exceed the 50 nL L^{-1} (ppb) threshold value in many parts of the world (WHO 2006)

Tropospheric ozone (O_3) is the most damaging air pollutant to crops and ecosystems. It is produced in the troposphere by catalytic reactions among nitrogen oxides (NOx = NO + NO2), carbon monoxide (CO), methane (CH4), and non-methane volatile organic compounds (NMVOCs) in the presence of sunlight. Ozone enters leaves through plant stomata during normal gas exchange. As a strong oxidant, ozone and its secondary byproducts damage vegetation by reducing photosynthesis and other important physiological functions, resulting in weaker, stunted plants, inferior crop quality, and decreased yields.



Source: Oksanen et al. (2013)

Figure 1: Monthly Mean Omi Tropospheric Column Ozone (In Dobson Units) Over Indian Region In 2011, Calculated From Satellite Based Data (TOMS.GSFC.NASA.GOV).

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From:
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Global studies relating to O_3-induced crop yield losses has shown that relative yield loss (RYL), crop production loss (CPL), and associated economic cost losses (ECL) are highest in India followed by China (Avnery et al. 2011). The highest wheat and rice losses were reported in India due to O_3 damage using M7 (ozone exposure time for 7 hrs during daylight) and AOT40 (accumulated ozone exposure above threshold of 40 ppb) indices (Van Dingenen et al. 2009).

In India, wheat is the most impacted crop with losses of 3.5 ± 0.8 million tons (Mt), followed by rice at 2.1 ± 0.8 Mt, mostly in central and north India. On the national scale, this loss is about 9.2% of the cereals required every year (61.2 Mt) under the provision of the recently implemented National Food Security Bill (in 2013) by the Government of India. The nationally aggregated yield loss is sufficient to feed about 94 million people living below poverty line in India (Gudhe et al. 2014)

Long-term exposure to high concentration of surface O_3 damages vegetation with substantial reduction in crop yields and crop quality (Morgan et al. 2006). This is a major concern for developing countries like India where expanding economy has led to rapid increases in ozone-precursor gases such as NOx, CO, and VOCs and resulted in the increased levels of ozone (Horowitz 2006). The highest winter wheat and rice losses occured in India, followed by China, Japan, and South Korea who are also experiencing similar wheat and rice losses on large scale in Asian region by damages due to increase of O_3 concentration (Wang et al. 2012).

Northern Hemisphere is now in the range of 35–40 ppb. High O_3 concentrations occur episodically throughout the year depending on the weather. During such episodes, O_3 concentrations can reach as high as 200 ppb as experienced in France during the 2003 heat wave. In some cities in the USA and Latin America (WHO 2006) and in metropolitan areas in Asia (Emberson et al. 2003) episodes of this magnitude are a common feature.

Where is Ground Level Ozone Found?

Many urban areas tend to have high levels of ground level ozone. But even rural areas are subjected to increased ozone levels because winds can carry ozone, and the pollutants that form O_3, hundreds of miles away from the original sources. Large amounts of NOx, transported from urban area, in presence of VOCs i.e naturaly released from trees, forms a large amount of ground level ozone in rural areas. Heavy use of nitrogen fertilisers further increases concentrations of ozone precursors, that finally effects the crop yield to a considerable extent.

Figure 2: Global ambient Ozone concentrations due to air pollution

Process of ozone production

Tropospheric O_3 is generated through photochemical reactions of O_3 precursors, i.e. nitrogen oxides (NOx), volatile organic compounds (VOC) including methane (CH_4), and carbon monoxide (CO). Background O_3 concentrations have risen from approximately 10 ppb before the industrial revolution, while daytime summer concentrations sometimes may exceed 40 ppb in many parts of the Northern Hemisphere (Vingarzan 2004).

Ozone has the same chemical structure (O_3) whether it occurs miles above the earth or at ground level. Being a major constituent of atmospheric smog, Groundlevel ozone is formed in the air by the photochemical reactions of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), i.e photochemically reactive hydrocarbons. VOCs, (volatile organic compounds) are widely used as ingredients in household products including; paints, varnishes, wax, fuels, cleaning, disinfecting, cosmetic, degreasing, and hobby products. Some VOCs are safe to handle and have little known health effects, while other VOCs are highly toxic. In addition to all of the man made sources of VOCs, plants are natural sources that release small amounts of VOCs.

NOx, (nitrogen oxide gases) is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts. Many of the nitrogen oxides are colorless and odorless. The primary sources of NOx are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. When high levels of VOCs and NOx are present in the air, they react and in the presence of sunlight and hot weather, ground level ozone forms. There are other factors involved with the formation of "bad" or ground level ozone, including; cloud cover, wind direction, and low wind speeds. If the weather conditions are conducive, and there are ample amounts of NOx and VOCs, harmful concentrations of ground level ozone can form in the air. Often industry is blamed entirely for emissions of ozone precursor, but actually private

Source:www.nctcog.org

Figure 3: Formation of Ozone

citizens are responsible for a significant percentage of the air pollutants that lead to ground level ozone production. Motor vehicle emissions are the single greatest contributor to ground level ozone pollution.

Factors affecting Tropospheric Ozone

The source gases responsible for the formation of O_3 may be present as a result of emissions within a region and also due to transport into the region of O_3 precursors. The rates of these processes and the overall O_3 budget depends on meteorological conditions such as solar intensity, temperature and pressure, and on the concentrations of O_3 precursor emissions and water vapour in the atmosphere. The other major source of O_3 in the troposphere is transport from the stratosphere. Moreover overuse of fossil fuels and nitrogen fertilizers results in increased concentration of this most damaging air pollution. In addition transboundry transport of O_3 precursor (NO_X) and volatile organic compounds (VOCs) in troposphere, result in higher O_3 concentration than critical level to plants in agriculture, forest and remote rural areas.

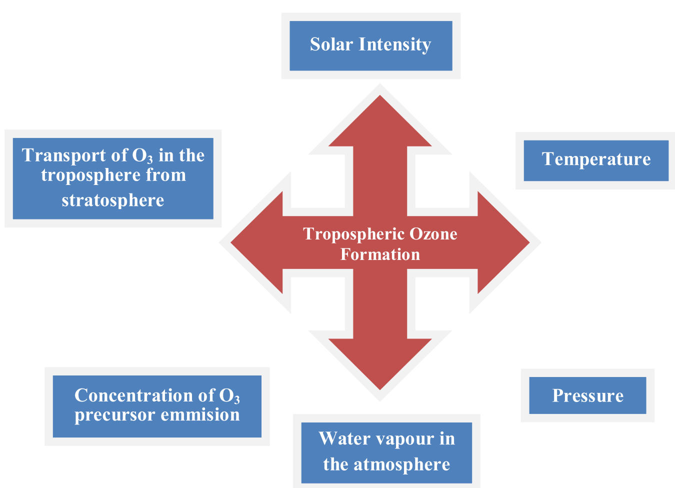


Figure 4: Factors affecting Tropospheric Ozone formation.

The lifetime and atmospheric budget of tropospheric ozone

Removal processes which are responsible for loss of ozone from the atmosphere determines its life time. The average lifetime of O_3 in the troposphere has been estimated at 22 (±2) days (Stevenson et al. 2006), but it varies with the altitude and ranges from 1–2 days in the boundary layer where dry deposition is the major sink, to several weeks in the upper troposphere. This, in combination with the potential for O_3 to be produced from precursors long after they have been emitted, makes O_3 a global pollutant.

The amount of O_3 in the atmosphere, or O_3 budget, is determined by the rates of O_3 production and destruction. Ozone production in the atmosphere has been estimated to account for approximately 4500 Tgy^{-1}. The net flux of O_3 from the stratosphere to the troposphere is approximately 540 Tgy^{-1}. The O_3 budget is closed by two loss processes: chemical destruction and dry deposition to the Earth's surface. Chemical loss or destruction in the atmosphere accounts for approximately 4100 Tgy^{-1} and deposition to the surface accounts for approximately 1000 Tgy^{-1} (Denman et al. 2007). Integrated over the whole troposphere, chemical production and loss rates are several times larger than the influx from the stratosphere and the surface deposition flux.

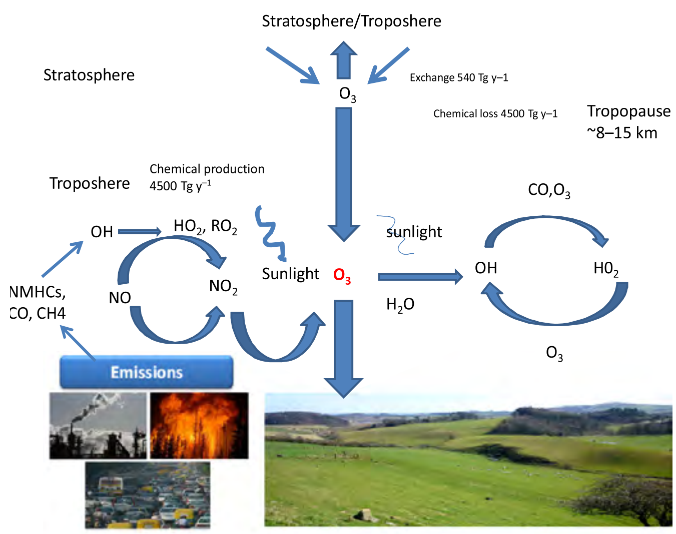
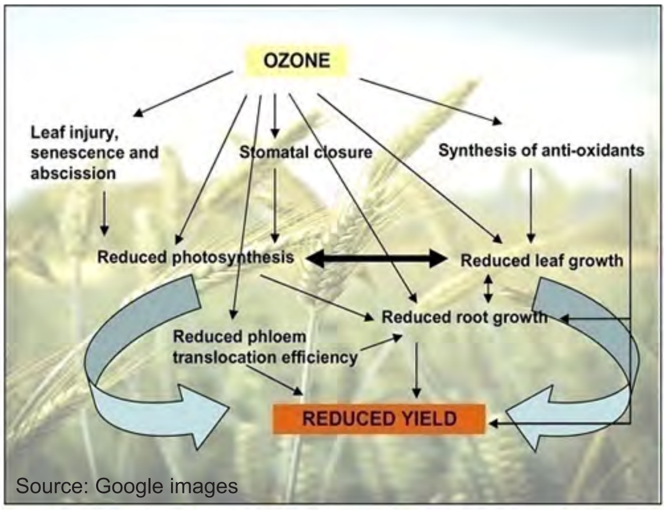


Figure 5: A systematic view of the sources and sinks of ozone in the troposphere.

Mechanism of Ozone damage to crop yield

Ground-level ozone (O_3) is an important regional to semi-global air pollutant and as well an anthropogenic greenhouse gas (Simpson et al. 2014). Ozone enters leaves through plant stomata during normal gas exchange. As a strong oxidant, ozone and its secondary byproducts damage vegetation by reducing photosynthesis and other important physiological functions, resulting in weaker, stunted plants, inferior crop quality, and decreased yields (Fuhrer 2009).



Source: Google images

Figure 6: Mechanism of Ozone damage to crop yield

Natural and anthropogenic emissions of ozone precursor compounds:

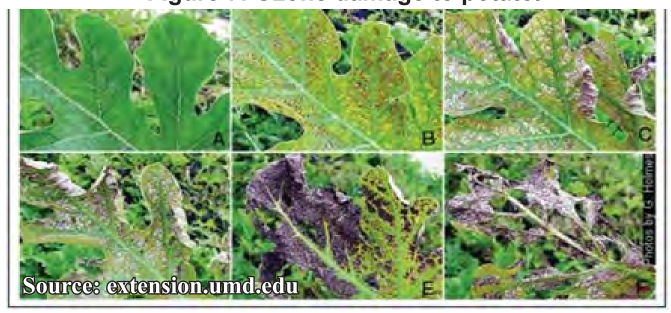
Both natural and anthropogenic sources contribute to the emission of ground-level ozone precursors, and the composition of emissions sources may show large variations across locations. Emission of VOCs from trees and plants may account for as much as two thirds of ambient VOCs in some locations (USEPA 1986). Anaerobic biological processes, lightning, and volcanic activity are the main natural contributors to atmospheric NOx, occasionally accounting for as much as 90% of all NOx emissions. Motor vehicles are the main anthropogenic sources of ground-level ozone precursors. Other anthropogenic sources of VOCs include emissions from the chemical and petroleum industries and from organic solvents in small stationary sources such as dry cleaners. Significant amounts of NOx originate from the combustion of fossil fuels in power plants, industrial processes, and home heaters.

The impacts of ozone on vegetation

- Acute visible injury, which for species with a market value dependent on their visible appearance, such as many horticultural crops, can cause an obvious and immediate loss of economic value.
- Effects in reducing photosynthetic rates and accelerating leaf senescence.
- It can also have direct effects on pollen germination and tube growth, fertilisation and the absission or abortion of flowers, pods and individual ovules or seeds. (Schoene et al. 2004)
- Significant effect on crop quality (Soja et al. 2004).
- Changes in foliar chemistry and surface characteristics caused by ozone can have a range of secondary effects, for example on the incidence of viral and fungal diseases and the impacts of insect pest.

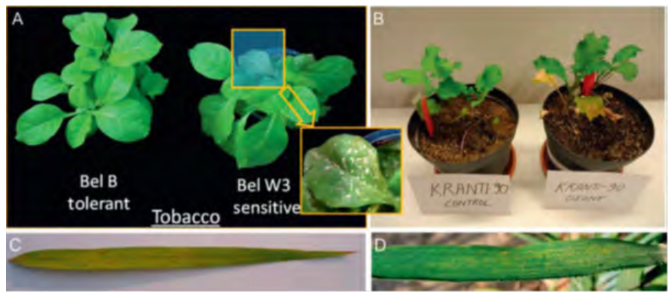

Source : www.earthobservatory.nasa.gov

Figure 7: Ozone damage to potato.



Source: extension.umd.edu

Figure 8: Progression of ozone damage on watermelon foliage



Source: Pandey et al. 2013

Figure 9: Ozone injury symptoms on different plant species. (A) Ozone sensitive (Bel W3) and tolerant (Bel B) varieties of tobacco plants (*Nicotiana tabacum* L.). (B) *Brassica juncea* var. Kranti (Indian mustard) exposed to 120 ppb O_3 for 5 days under controlled conditions. (C) *Oryza sativa* var. Sugandha. (D) *Triticum aestivum* var. HUW 234. ((A), (C) and (D) grown under ambient conditions at Lucknow, India; O_3 concentration ranged from 26 to 78 ppb (average 60 ppb).

The impact of the exposure of plants to ground-level ozone depends not only on the duration and concentration of exposure but also on its frequency, the interval between exposures, the time of day and the season, site-specific conditions, and the developmental stage of plants. Furthermore, ground-level ozone is part of a complex relationship among several air pollutants.

Table: 1 Yield loss due to surface ozone in different Asian countries

Country	Crop	Average Ozone concentration (ppb)	Yield reduction (%)	References
Pakistan	Soyabean	33-63	64	Wahid et al (2001)
	Barley	71	13-44	Wahid (2006)
India	Wheat	40-48	11-21	Rai et al (2007)
	Wheat	40-48	5-48	Oksanen et al.(2013)
	Rice	40-48	3-18	Oksanen et al.(2013)
	Soyabean	40-48	3-19	Oksanen et al.(2013)
	Bean	40-48	13-26	Oksanen et al.(2013)
	Mustard	62	20	Agarwal et al (2003)
	Mungbean	10-59	18-79	Agarwal et al (2006)
Malaysia	Rice	32.5	6.3	Ishii et al (2004)
China	Rice	23-39	14-20	Chen et al (2008)

Table: 2 Regionally aggregated Relative yield loss (RYL), for wheat, rice, maize and soyabean (global overview) (Avnery et al 2011)

	World	European Union	North America	China	India
Wheat					
AOT40[a]	12.3%	4.1%	4.1%	19.0%	27.6%
M7[b]	7.3%	4.6%	4.4%	9.8%	13.2%
Rice					
AOT40	3.7%	4.7%	3.2%	3.9%	8.3%
M7	2.8%	3.5%	2.6%	3.1%	5.7%
Maize					
AOT40	2.4%	3.1%	2.2%	4.7%	2.0%
M7	4.1%	5.1%	3.6%	7.1%	4.0%
Soyabean					
AOT40	5.4%	20.5%	7.1%	11.4%	4.7%
M12	15.6%	27.3%	17.7%	20.8%	19.1%

a- accumulated ozone exposure above threshold of 40 ppb
b- ozone exposure time for 7 hrs during daylight (8:00-14:59)

Table: 3 Yield Losses due to Surface Ozone in Different Crops in India (Derived from Field Experiments, Open-Top Chamber and EDU (ethylene diurea) Treatment Studies (Pandey et al. 2013))

Species	Average ozone concentration (ppb)	Yield reduction	References
Wheat (*Triticum astivum)*	10-59	25[a]	Agarwal et al. (2003)
	70	9[a]	Ambasht & Agarwal (2003)
	10-41	25-32[a]	Rajput & Agarwal (2005)
	40-48	11-12[b]	Rai et al. (2007)
	35-54	2-25[c]	Singh & Agarwal (2009)
	45-57	11-46[b]	Sarkar & Agarwal (2010)
	5-55	18-24[b]	Sarkar et al. (2010)
Rice(*Oryza sativa*)	23-45	11-16[b]	Rai & Agarwal (2008)
	20-55	7-9[b]	Rai et al. (2010)
	7-35	32[c]	Agarwal et al. (2005)
	10-59	18-79[a]	Agarwal et al. (2006)
	62	20[a]	Agarwal et al. (2003)
	42-54	17[c]	Singh et al. (2009)
	28-59	7-19[b]	Singh et al. (2012)
Black gram(*Vigna mungo*)	41-60	8-24[c]	Singh et al. (2010)

a field studies b open top chamber studies c EDU treatment studies

Conclusion

Widespread ozone pollution under present emission scenario has considerable impact on productivity of crops important for food security in India. The agriculturally important Indo-Gangetic Plain is mainly exposed to the threat posed by ground level ozone. The O_3 induced damage to crops is expected to offset a significant portion of the GDP growth rate, especially in countries with an economy based on agricultural production such as those that dominate the South Asian region including India.

The present-day ozone-induced damage to wheat (3.5± 0.8 Mt) and rice (2.1 ± 0.8 Mt) is sufficient enough to feed roughly 35% (94 million people) of 270 million below poverty line population in India. Moreover, ozone concentrations are expected to rise in developing countries due to increased emissions of nitrogen oxides and other ozone precursors resulting from rapid industrialization.

Patterns of global exposures to ozone are likely to change dramatically over the next 50 years and may act as a significant constraint on global food production and ecosystem function. The extent to which ozone exposures increase over this period is closely linked to the emission scenarios for energy production, transport, agriculture and industry, which forms the basis for predictions of the impacts of climate change.

There is currently no air quality standards in India designed to protect agriculture from the effects of ground-level ozone pollution. There should be co-ordinated and standardised ozone monitoring across the country and study of potential indirect effects of zone on crop yeild and crop quality should be studied in detail.

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ABSTRACTS

Assessment of crop yield losses in Punjab and Haryana using two years of continuous in-situ ozone measurements

B. Sinha , K. Singh Sangwan , Y. Maurya1 , V. Kumar , C. Sarkar , B. P. Chandra , and V. Sinha

ACPD 15, 2355–2404, 2015

In this study we use a high quality dataset of in-situ ozone measurements at a suburban site called Mohali in the state of Punjab to estimate ozone related crop yield losses for wheat, rice, cotton and maize for Punjab and the neighboring state Haryana for the 5 years 2011–2013. We inter-compare crop yield loss estimates according to different exposure metrics such as AOT40 and M7 for the two major crop growing seasons of Kharif (June–October) and Rabi (November–April) and establish a new crop yield exposure relationship for South Asian wheat and rice cultivars. These are a factor of two more sensitive to ozone induced crop yield losses compared to their European and 10 American counterparts. Relative yield losses based on the AOT40 metrics ranged from 27–41 % for wheat, 21–26 % for rice, 9–11 % for maize and 47–58 % for cotton. Crop production losses for wheat amounted to 20.8 million t in fiscal year 2012–2013 and 10.3 million t in fiscal year 2013–2014 for Punjab and Haryana jointly. Crop production losses for rice totalled 15 5.4 million t in fiscal year 2012–2013 and 3.2 million t year 2013–2014 for Punjab and Haryana jointly. The Indian National Food Security Ordinance entitles 820 million of India's poor to purchase about 60 kg of rice/wheat per person annually at subsidized rates. The scheme requires 27.6 Mt of wheat and 33.6 Mt of rice per year. Mitigation of ozone related crop production losses in Punjab and Haryana alone could provide 20 >50 % of the wheat and 10 % of the rice required for the scheme. The total economic cost losses in Punjab and Haryana amounted to USD 6.5 billion in the fiscal year 2012–2013 and USD 3.7 billion in the fiscal year 2013–2014. This economic loss estimate represents a very conservative lower limit based on the minimum support price of the crop, which is lower than the actual production costs. The upper 25 limit for ozone related crop yield losses in entire India currently amounts to 3.5–20 % of India's GDP. Mitigation of high surface ozone would require relatively little investment in comparison to economic losses incurred presently. Co-benefits of ozone mitigation also include a decrease in the ozone related mortality, morbidity and a reduction of the ozone induced warming in the lower troposphere.

Effects of ozone on growth, net photosynthesis and yield of two African varieties of *Vigna unguiculata*

Rashied Tetteh, Masahiro Yamaguchi, Yoshiharu Wada, Ryo Funada, Takeshi Izuta

Environmental Pollution 197 (2015)

We synthesized the effects of ozone on wheat quality based on 42 experiments performed in Asia, Europe and North America. Data were analysed using meta-analysis and by deriving response functions between observed effects and daytime ozone concentration. There was a strong negative effect on 1000- grain weight and weaker but significant negative effects on starch concentration and volume weight. For protein and several nutritionally important minerals (K, Mg, Ca, P, Zn, Mn, Cu) concentration was significantly increased, but yields were significantly decreased by ozone. For other minerals (Fe, S, Na) effects were not significant or results inconclusive. The concentration and yield of potentially toxic Cd were negatively affected by ozone. Some baking properties (Zeleny value, Hagberg falling number) were positively influenced by ozone. Effects were similar in different exposure systems and for spring and winter wheat. Ozone effects on quality should be considered in future assessments of food security/ safety.

Ground-level O_3 pollution and its impacts on food crops in China: A review

Zhaozhong Feng, , Enzhu Hu, Xiaoke Wang, Lijun Jiang, Xuejun Liu

Environmental Pollution 199 (2015)

Ground-level ozone (O_3) pollution has become one of the top environmental issues in China, especially in those economically vibrant and densely populated regions. In this paper, we reviewed studies on the O_3concentration observation and O_3 effects on food crops throughout China. Data from 118 O_3 monitoring sites reported in the literature show that the variability of O_3 concentration is a function of geographic location. The impacts of O_3 on food crops (wheat and rice) were studied at five sites, equipped with Open Top Chamber or O_3-FACE (free-air O_3 concentration enrichment) system. Based on exposure concentration and stomatal O_3 flux–response relationships obtained from the O_3-FACE experimental results in China, we found that throughout China current and future O_3 levels induce wheat yield loss by 6.4–14.9% and 14.8–23.0% respectively. Some policies to reduce ozone pollution and impacts are suggested.

NEWS

Air pollution hits crops more than climate change

Atmospheric pollutants may impact India's major crops like wheat and rice more than temperature rise, says a new study based on a 'regression model' that predicts future events with information on past or present events. The study by Jennifer Burney and V. Ramanathan, scientists at the University of California, project that a one degree centigrade rise in temperature could lead to a crop decline of four per cent for wheat and five per cent for rice. But losses from pollution could be greater. “For context, the yield loss for wheat attributable to pollutants alone in 2010 corresponds to over 24 million tons of wheat: around four times India's wheat imports before the 2007—2008 food price crisis and a value greater than $5 billion,” the authors write in a paper on the study published November in *Proceedings of the National Academy of Sciences*. Most pollutants impact temperature by absorbing incoming radiation from the sun and reflected heat from the earth. Black carbon aerosols and ozone are of special concern as they affect crops directly — black carbon changes the amount of radiation reaching the surface while ozone is toxic to plants. In 2010, wheat yields were 36 per cent lower and the models show that 90 per cent of that change was due to the pollutants. The impact was most drastic in the state of Uttaranchal and Uttar Pradesh. Wheat yields in Uttar Pradesh were 50 per cent lower than they would have been without the current climate and pollutant trends with two-thirds of the decrease attributable to pollutant levels. In the case of rice, 15 per cent of yield decrease in the Gangetic plains could be attributed to pollutants. The Gangetic plains seem to accumulate surface level ozone and aerosols before the monsoon.

Source: scidev.net

Air pollution in India cuts wheat yields by half: Study

Air pollution in India is impacting the productivity of wheat crops, reducing it by almost half, a research paper has said that India has already been negatively affected by recent climate trends, the paper said the significant decreases in yield could be attributed to two air pollutants -- black carbon and ground level ozone.

Source: googlenews.com

BOOKS

Turn Down the Heat: Confronting the New Climate Normal
ISBN: 1464804370,
Publisher: World Bank Publications, 2014
Author: World Bank Publications

Climate change effect on crop productivity
ISBN: 9781482229202
PublisherCRC Press 2014
Author: Rakesh S. Sengar & Kalpana Sengar

State of the World 2015: Confronting Hidden Threats to Sustainability State of the World
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CPEP 2015: 17th International Conference on Plants and Environmental Pollution
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Date: 5 - 6 November, 2015
Website: https://www.waset.org/conference/2015/11/cape-town ICPEP

IPPCongress — 3rd international Plant Physiology Congress: Challenges and Strategies in Plant Biology Research
Venue: New Delhi, India
Date: 11-14 December 2015
Website: http://www.ippcongress.in

International Conference on Climate Change & Sustainability
Venue: Mumbai, Maharashta, India
Date: 21 Dec 2015-23 Dec 2015
Website: http://ic3s.in

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