Air Pollution Effects on Rice Yields in South Asia

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Outline

Introduction
- -Why Rice
- -Why South Asia

Main Pollutants
- Chemical Process
- Expected Pollutants Increases
- Effect on Rice Yields

Aerosols
- Chemical Process
- Effect on Visibility and UV
- Effects on Rice Yields

Temperature
- Chemical Process
- Expected Temperature Increases
- Effects on Rice Yields

Rice Pathogens
- Brief Introduction
- Atmospheric Factors
- Effects on Rice Yields

Conclusion

Why rice?

-Staple Crop

-50% of calories

-Bangladesh, Cambodia, Myanmar, Laos, Vietnam

-20-45% of calories

-Thailand, Philippines, Malaysia, India, Nepal, Sri Lanka

-Annually 37% of crop lost worldwide

-120-200 million tons

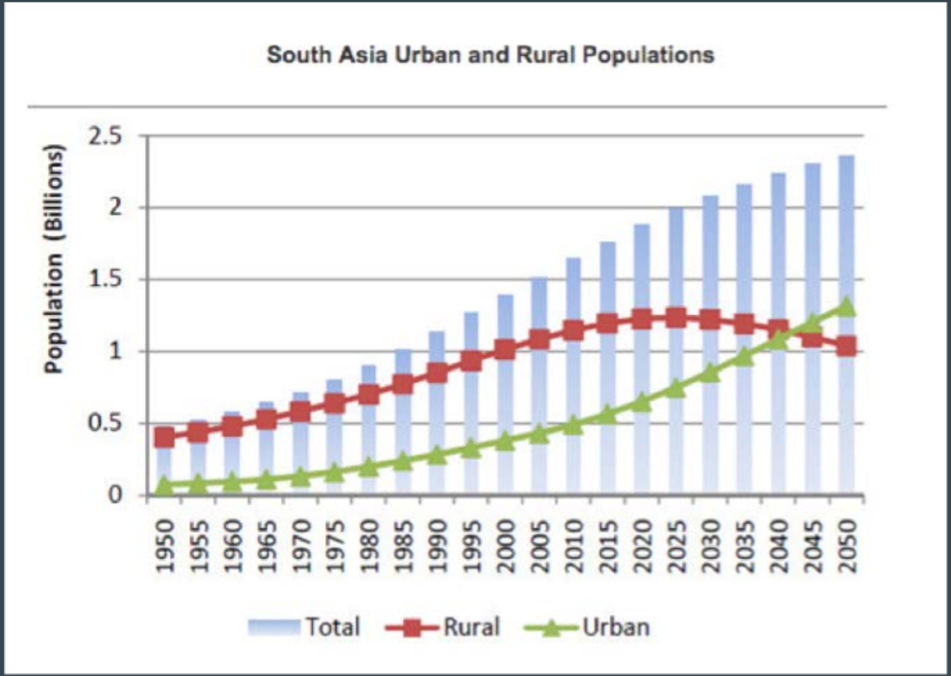
-10-15% of losses from disease

South Asia

Southern region of the Asian continent:
-Afghanistan
-Bangladesh
-India
-Nepal
-Pakistan
-Bhutan
-Sri Lanka
-Maldives

http://2012books.lardbucket.org/books/regional-geography-of-the-world-globalization-people-and-places/section_12/3f53c3b826f8bd5c8d7f67654c0d3438.jpg

Why South Asia?



Critical Population Group:

-Population of 1.721 billion (as of 2014)

-India projected to pass China as the world's most populous country by 2028

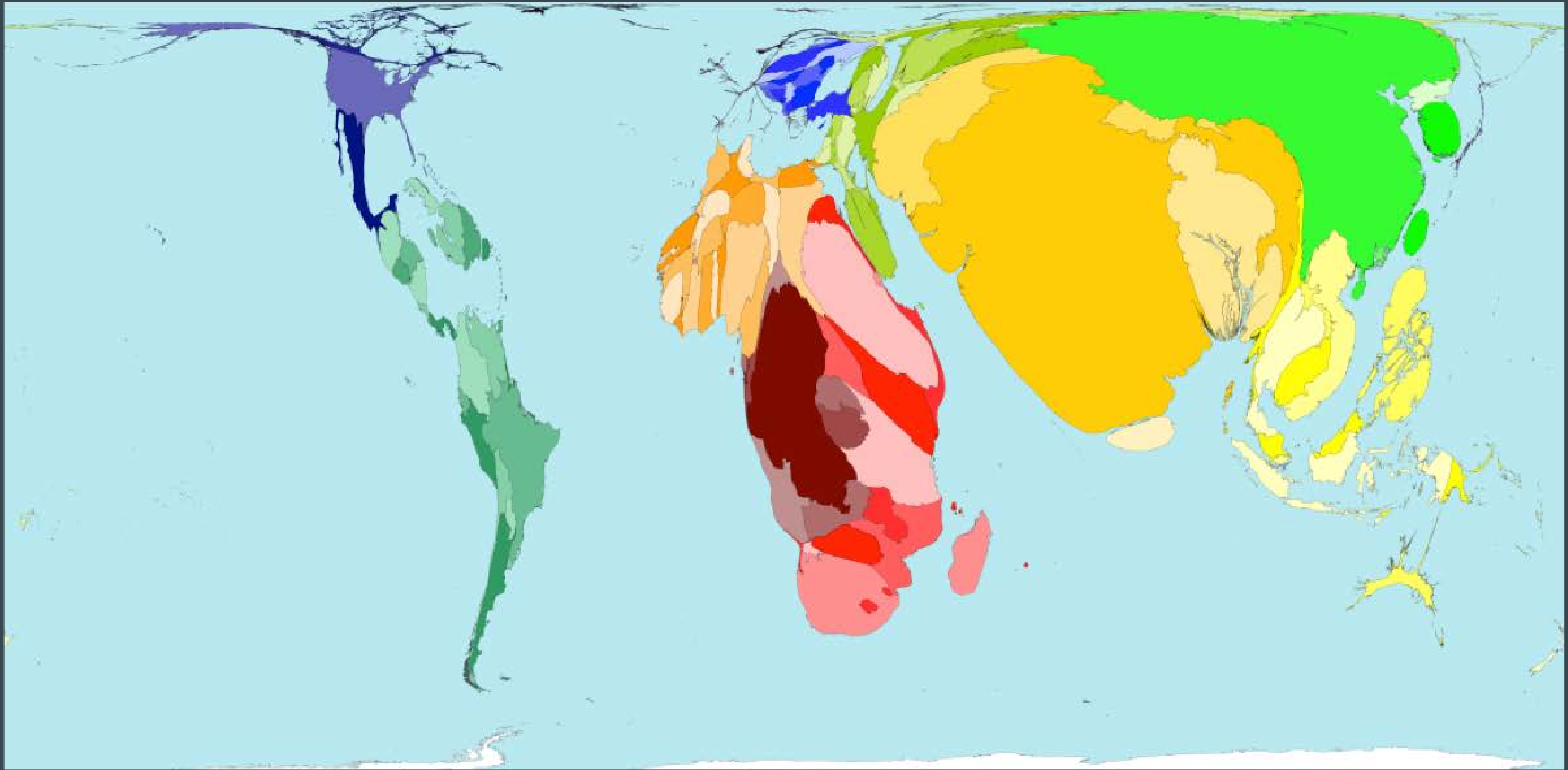
-largest working age population

-rural to urban migration

http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/0,,contentMDK:22593033~pagePK:146736~piPK:146830~theSitePK:223547,00.html

Undernourished Population

http://www.state.gov/s/globalfoodsecurity/129573.htm



Rice & South Asia

-Staple Food

-Livelihood for 50 million households

-Cultural significance

-Rice Production

  -32% of global yield

  -37.5% of global area

-Production increased 300% since green revolution

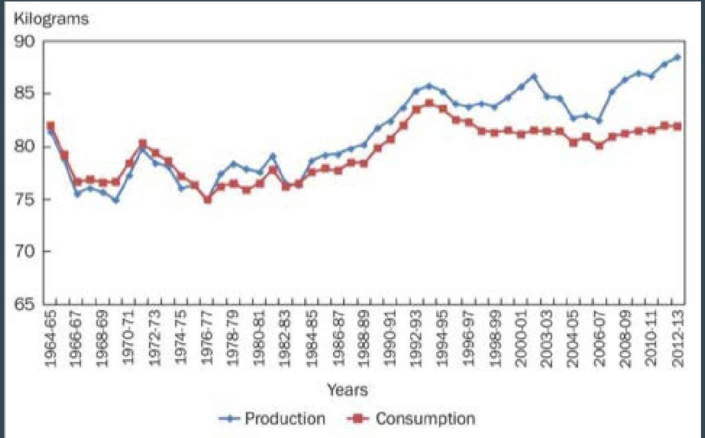


Fig. 1. South Asian rice production and consumption on a per capita basis.*

*5-year moving average

Data Source: USDA & UN

Images courtesy of World Bank

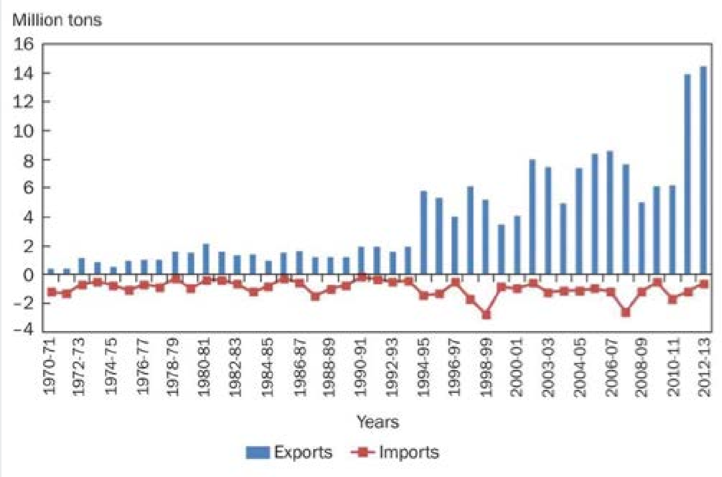
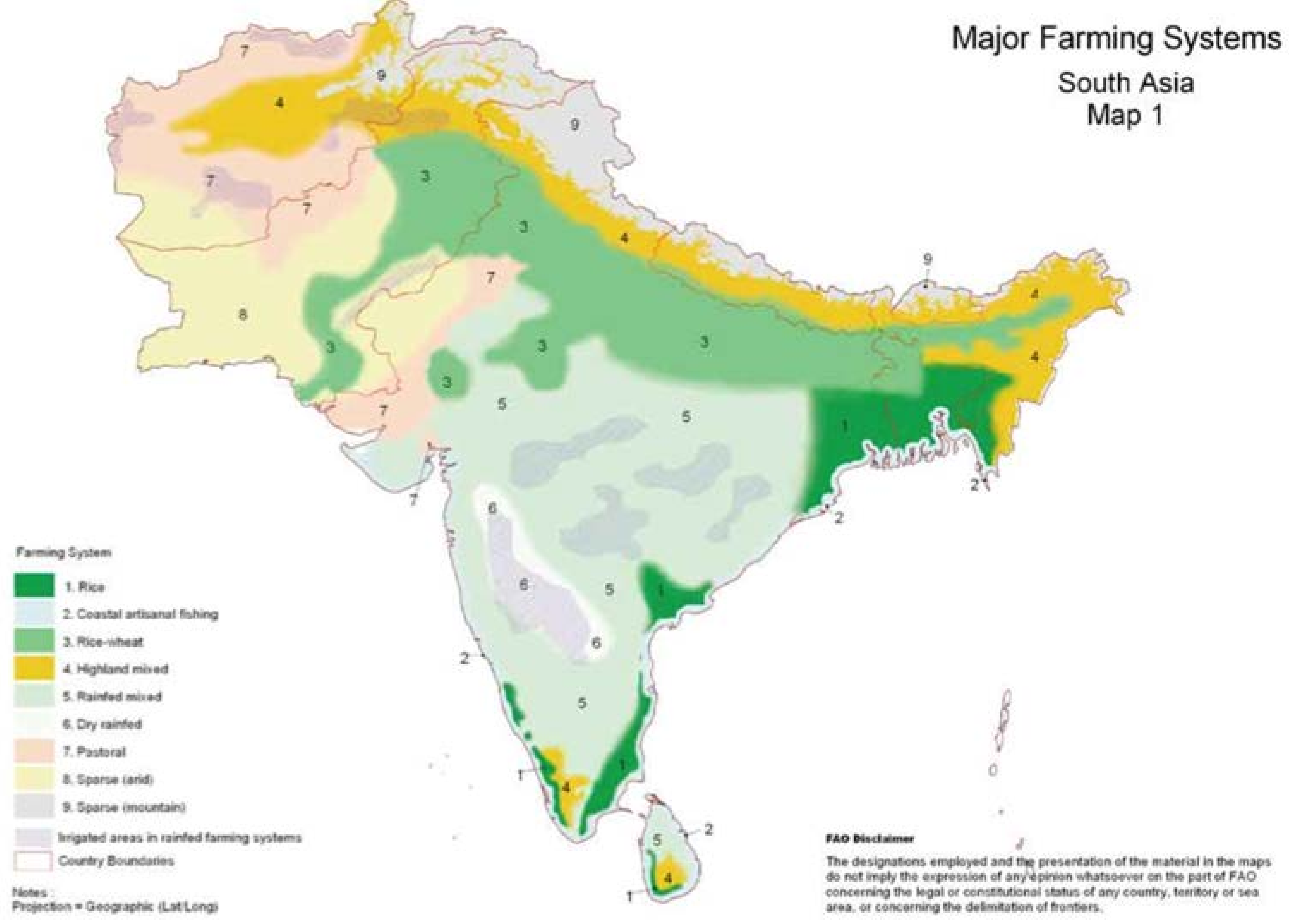


Fig. 2. South Asian rice trade.

Food Security In South Asia



http://www.fao.org/docrep/003/y1860e/y1860e07.htm

Main Pollutants

...

By: Congmeng Lyu

Major pollutants:

Ozone

Sulfur dioxide

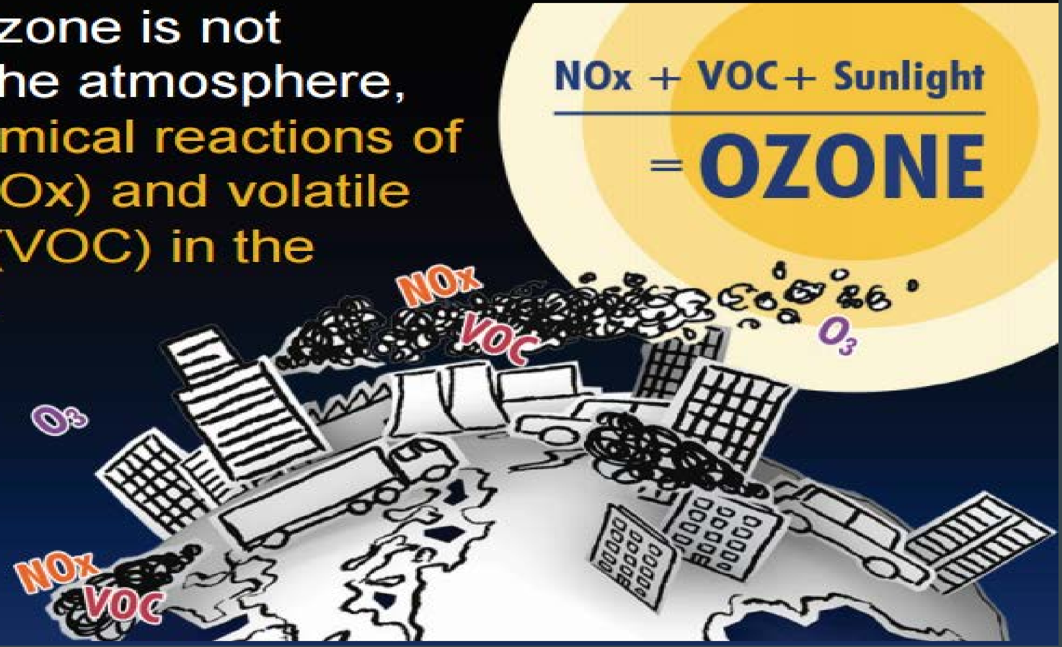
NOx (NO_2 mainly)

Fluorides

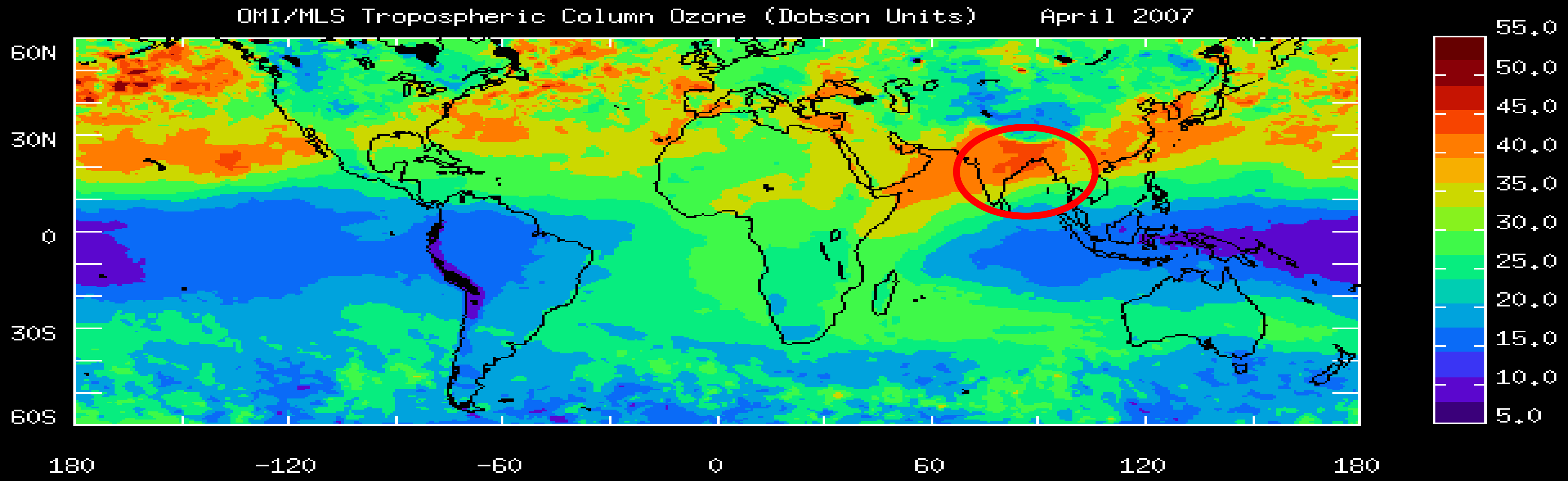
O_3

Formation:

Ground level or "bad" ozone is not emitted directly into the atmosphere, but is created by chemical reactions of oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence 中 sunlight.



Tropospheric O_3 distribution

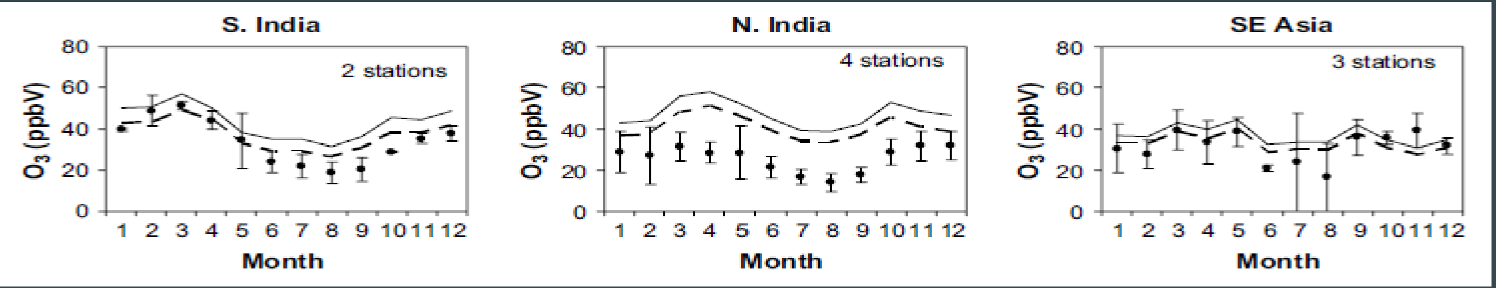


Ground level O_3 trend

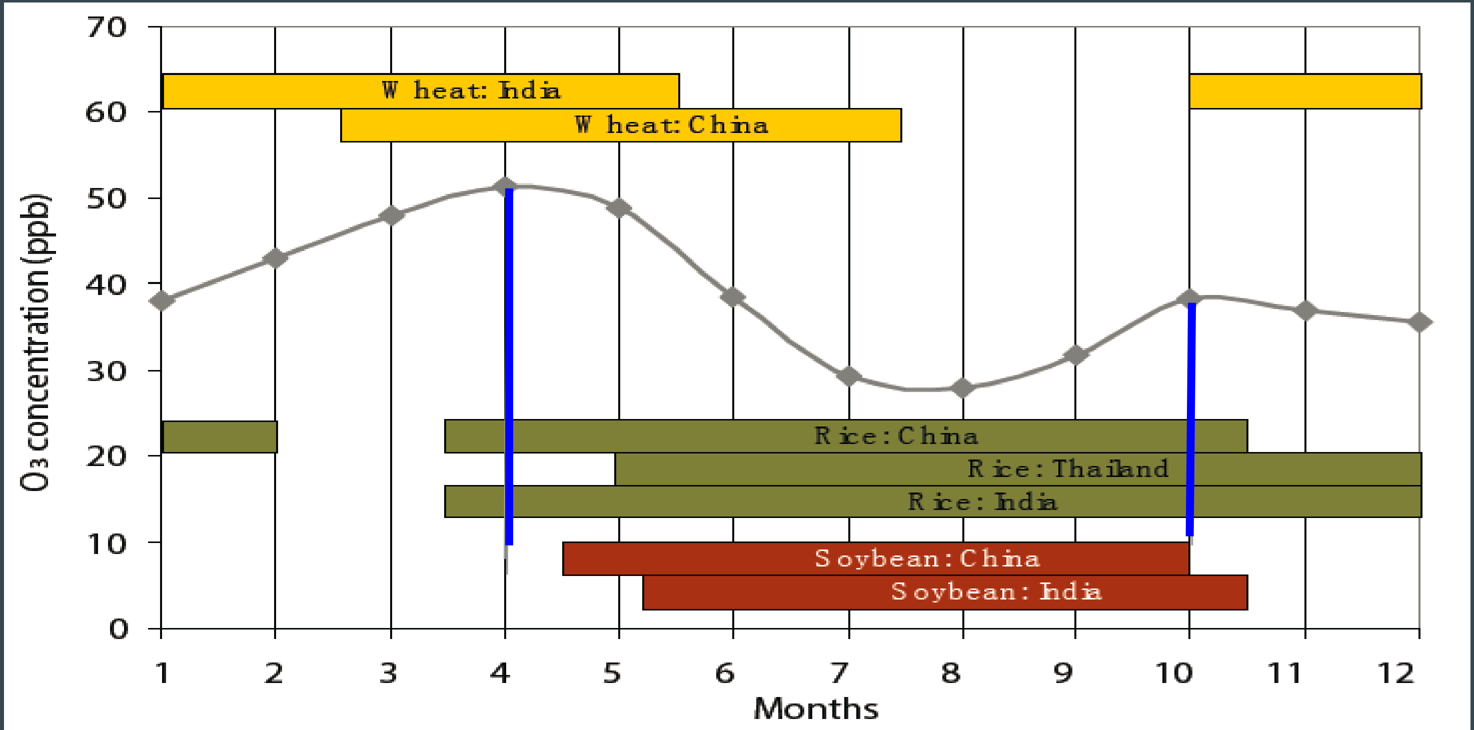
Year by year trend:

Ground level ozone concentrations are expected to rise in South Asia due to increased emissions of NOx and other ozone precursors resulting from rapid industrialization.

Month by month trends：



Ozone seasonal variation and crops cycle in South Asia



Why ozone can impact rice yields?

- 1. O_3 enters the leaves through the stomates, and cause visible injury to the leaves.

- 2.Photosynthesis reduced, because chloroplast outer membrane decomposed, chlorophyll and proteins related to photosynthesis decreased.
- 3. Reduced carbon uptake caused by reduced photosynthesis lead to lowered carbon transport to roots, the growth of root is inhibited and consequently less nutrients will be assimilated from the ground, as a result the growth rate of rice is decreased.
- 4. Producing period of rice is reduced by the impact of ozone.

So rice yield is reduced.

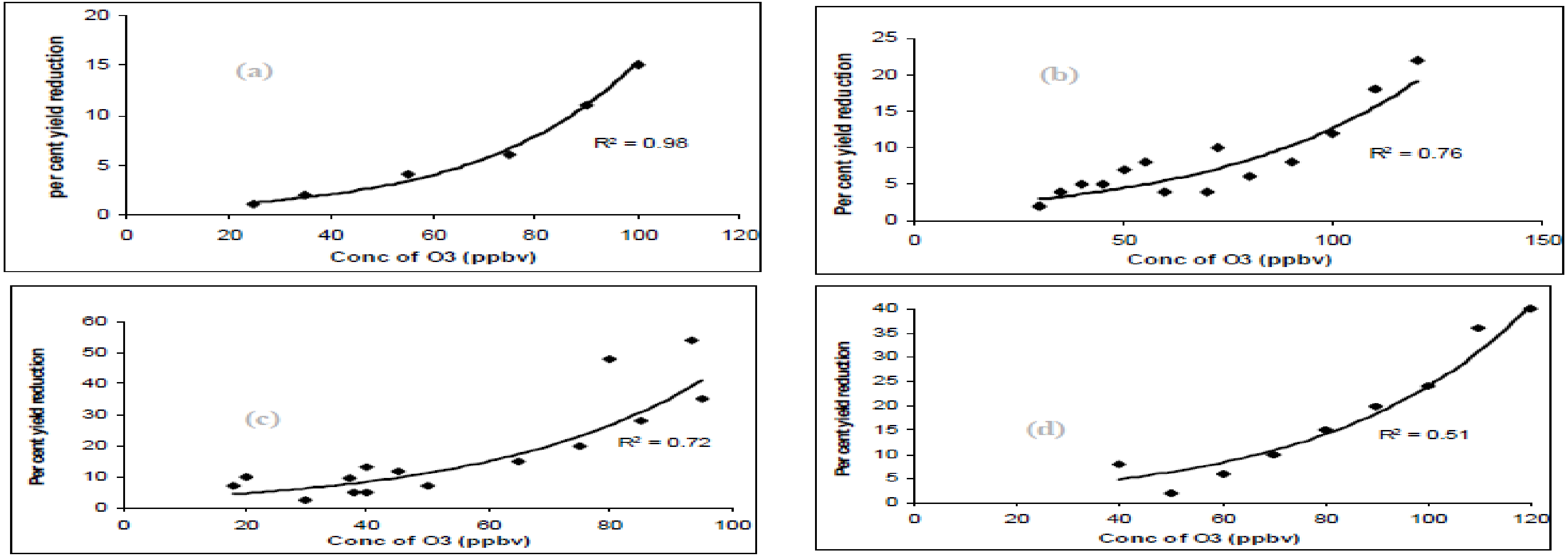
Examples

Ambient Air Pollution Effects on Crop

SOME KNOWN STUDY AROUND ASIA

Country	Pollutant	Crop	Yield loss	References
Japan (Kanton)	O_3 (40-60 ppb)	Rice	0– 7%	Kobayashi (1999)
China (7 provinces) (south west)	SO_2 and acid rain	Vegetables	7.8 %	Feng *et al.*(1999)
		Wheat	5.41 %	
		Soybean	5.73 %	
		Cotton	4.99 %	
	O_3 (ppb) (night 15 mid day max 75)	Green pepper	Sensitive	Zheng *et al.* (1998)
			"	
		Rice	"	
		Cauliflower	"	
		Aubergine		
Taiwan (S) Taipei Basin	O_3	Spinach	"	Sun (1993)
		Sweat potato	"	
China, Japan and South Korea	O_3 50– 55 ppb (1990)	Corn		
		Rice	1– 9 %	Wang and Mauzerall, 2004)*
		Wheat		
		Soybean	23– 27 %	
		Corn		
		Rice	2– 16 %	"
	60– 65 ppb (2020)	Wheat		
		Soybean	28– 35 %	

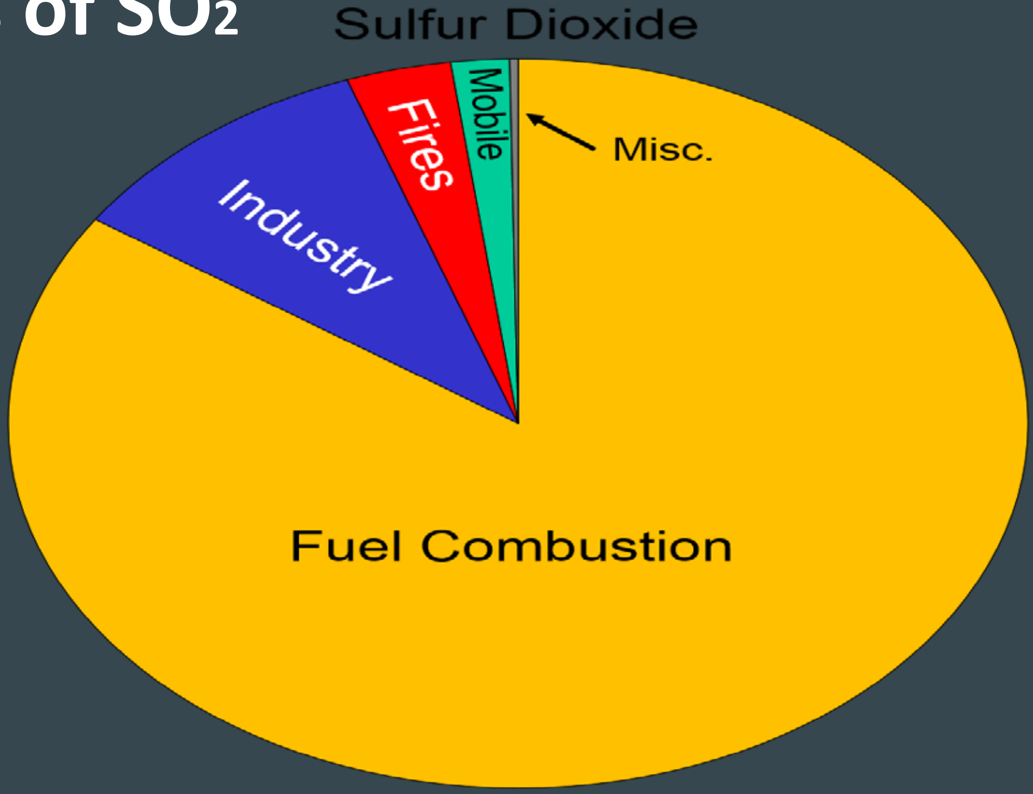
examples



Response of O_3 exposure to yield of (a) rice, (b) corn, (c) spring and (d) winter wheat

Sulfur Dioxide

Sources of SO_2



Global SO_2 emission trend

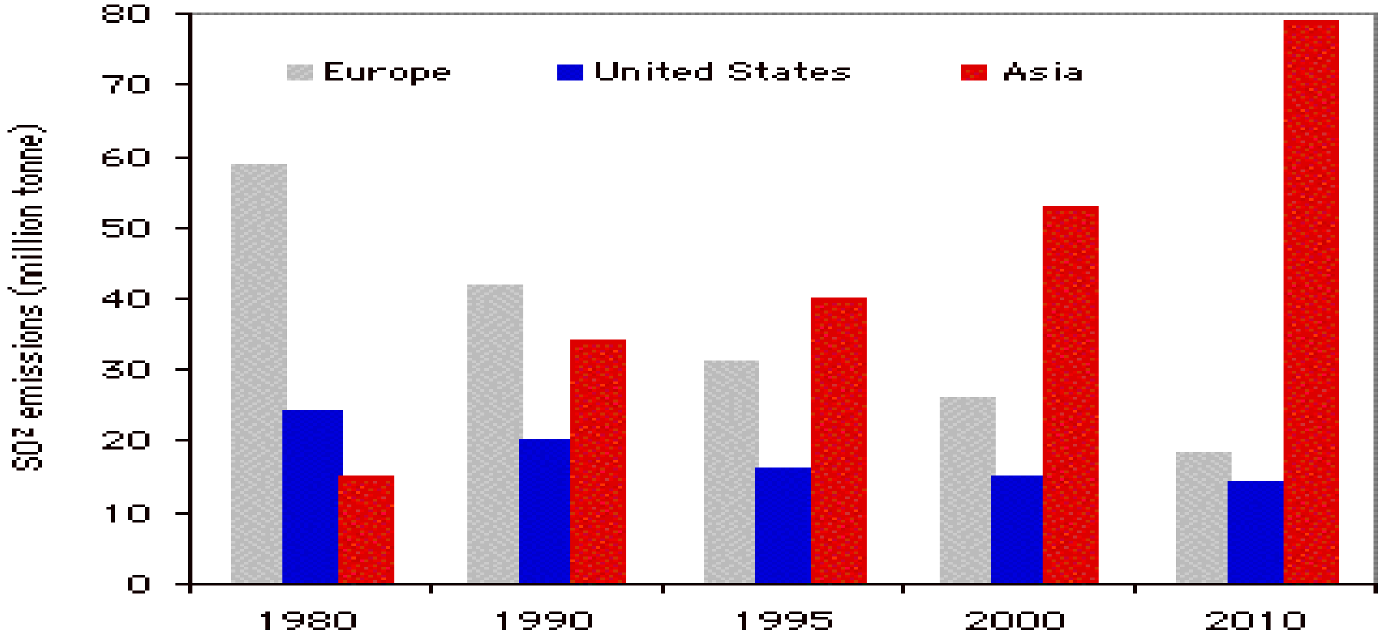
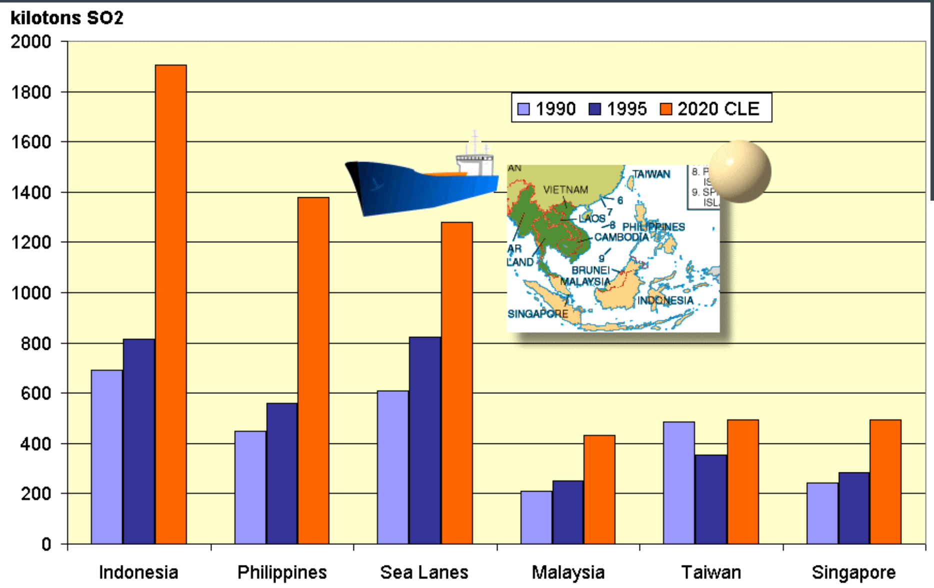
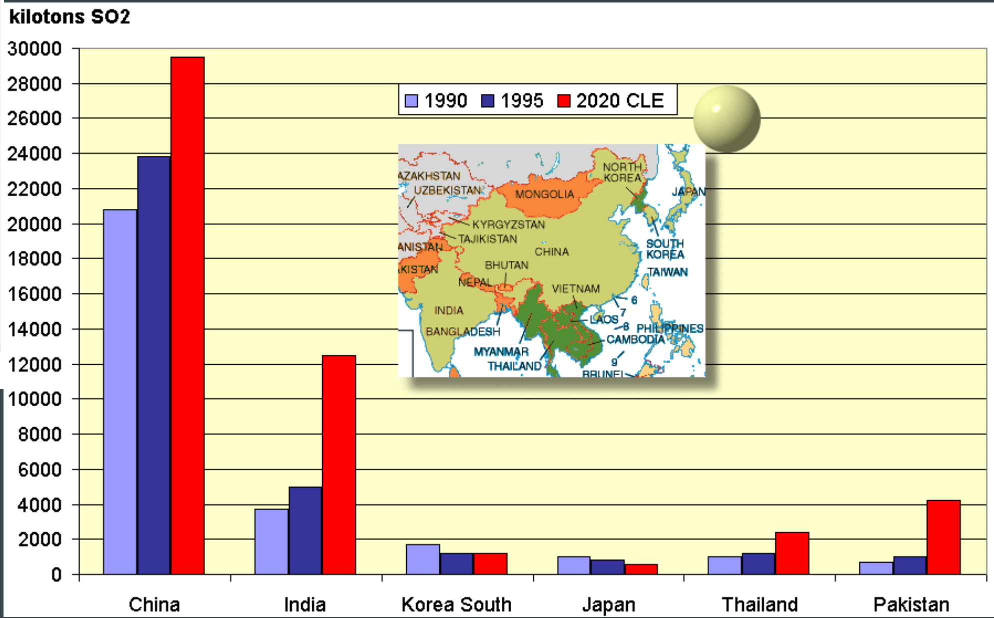


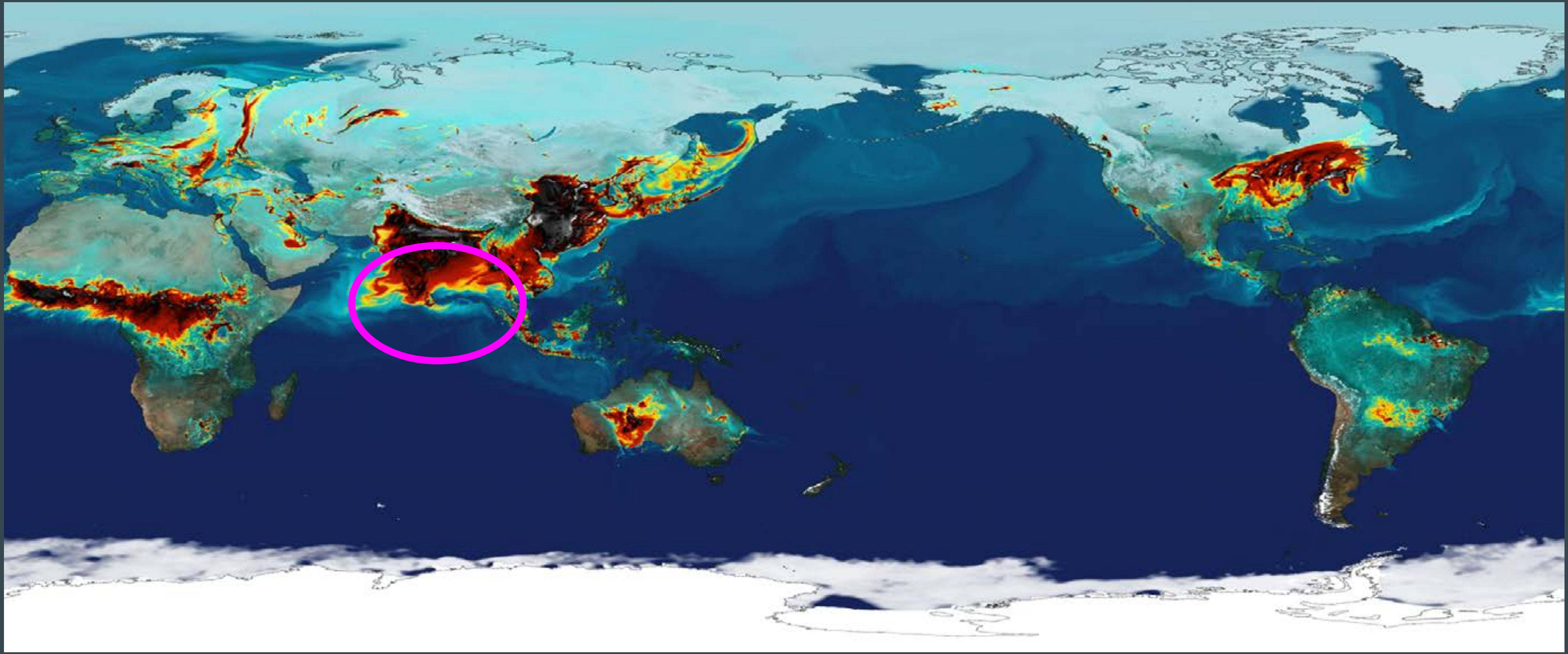
Fig. 6. Comparison of SO_2 emissions from Asia, Europe, and the United States in different decades (data from Worldwatch Institute 1998).

Asian SO_2 emission trend





Simulated global distribution of SO_2



South Asia is under serious SO_2 pollution

Why SO_2 can impact rice yields?

Mechanism:

SO_2 enters the leaves mainly through the stomata.

1.Causes general water stress in plants by reducing stomatal opening.

2.Changes the membrane permeability by affecting structural proteins in the cell membrane.

3. Reduces the synthesis of proteins and enzymes by interferes with amino acid metabolism.

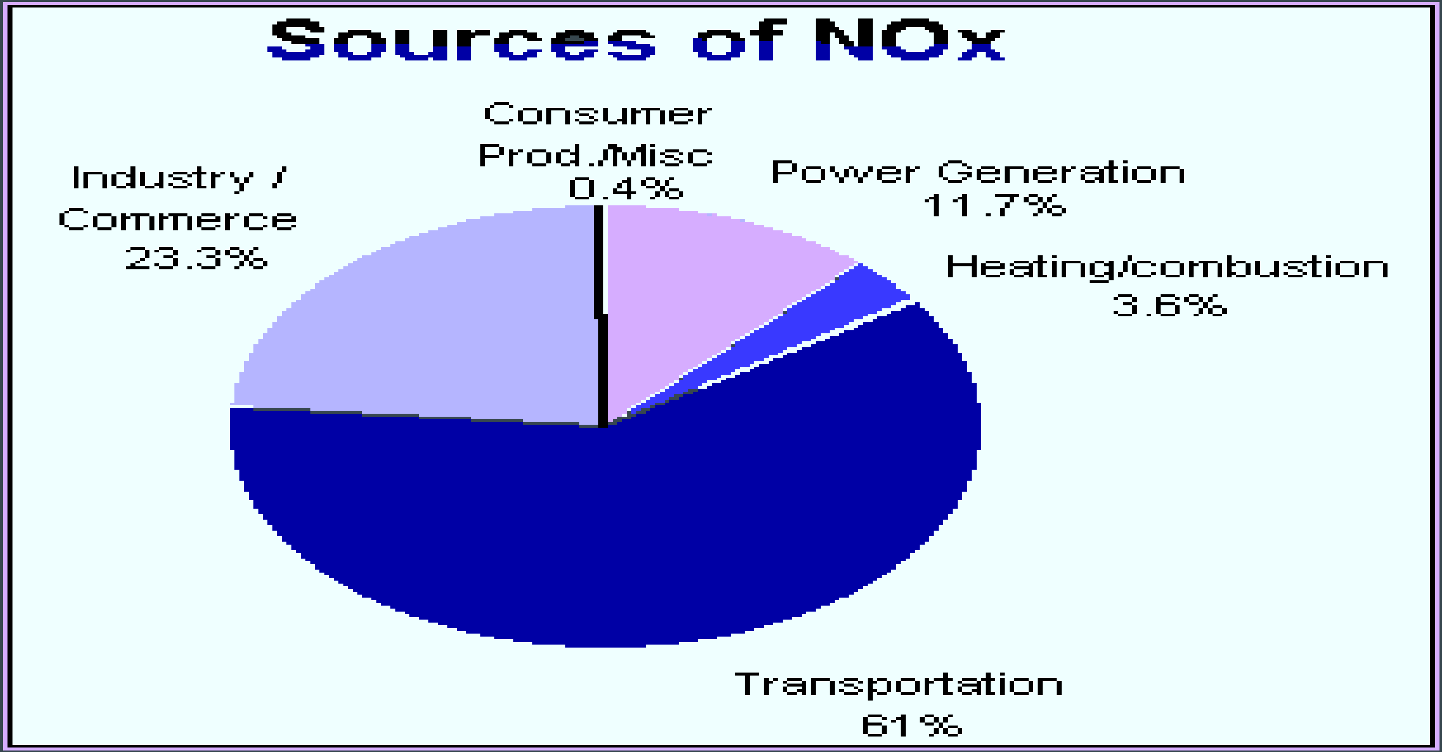
4.Inactivates many enzymes either by breaking their S-S bonds or by changing their stereo structure.

5.Reduces photosynthesis and increases respiration.

Symptoms and effects:

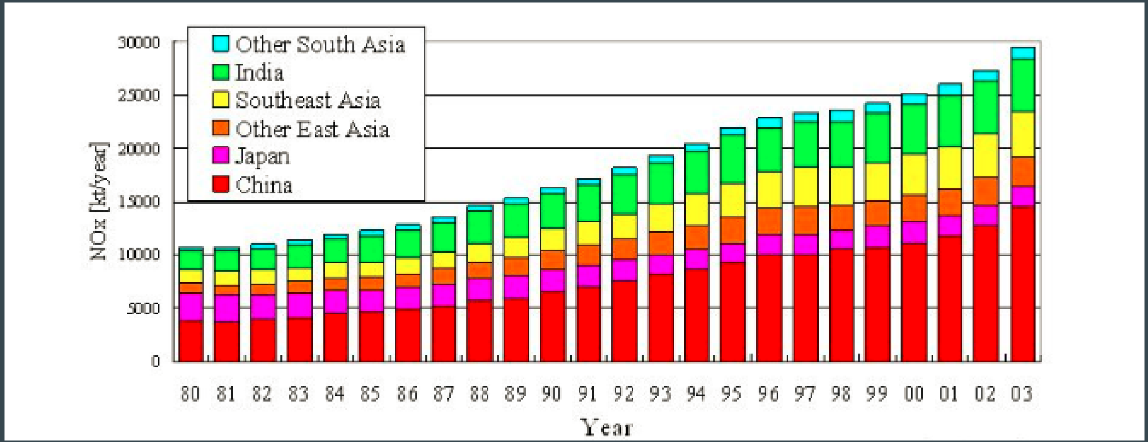
- Exposed leaves can begin to lose their color in irregular, blotchy white spots. Some leaves can develop red, brown or black spots.
- When the pigments in enough tissue are damaged or killed, plants can begin to lose their leaves. Crop output is greatly reduced and growth can be stunted. This is especially noticeable in young plants.

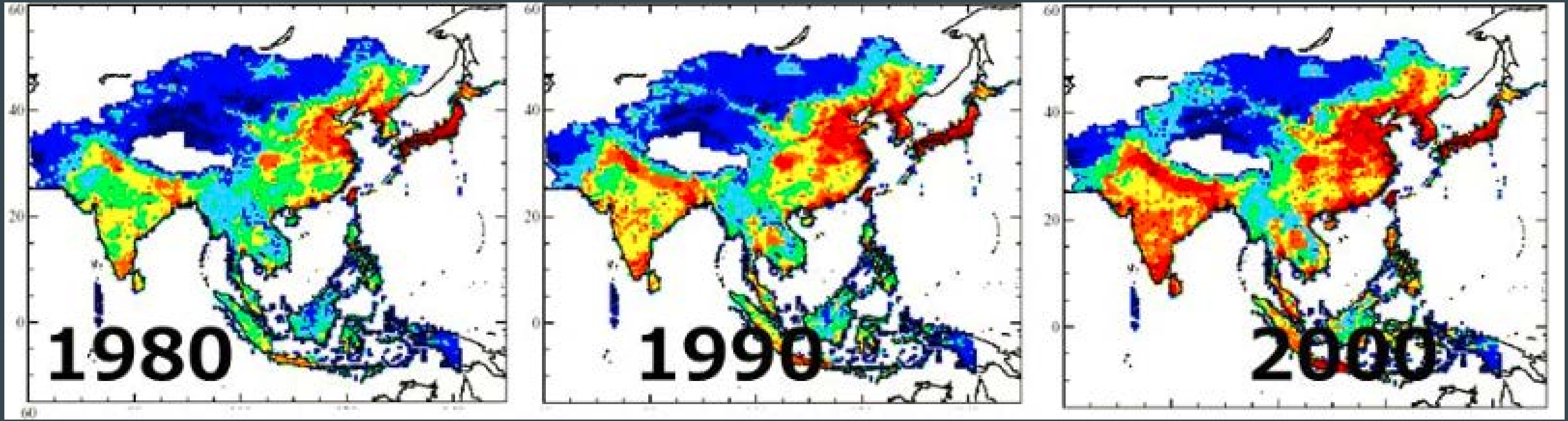
NOx



Sources of NOx
Consumer Prod./Misc 0.4%
Industry / Commerce 23.3%
Power Generation 11.7%
Heating/combustion 3.6%
Transportation 61%

Trend of NOx emission in Asia





Why NOx can impact rice yields ?

Mechanism:

Reduced photosynthesis: NO_2 causes formation of crystalloid structures in the stroma of chloroplasts and swelling of thylakoid membrane.

Symptom:

Chlorosis in leaves: most of the angiosperm species produce water-soaked intravenous areas that later become necrotic.

Effects:

NO_2 mostly affects the leaves and seedlings. Reduced photosynthesis ultimately lead to the reduction in yields.

Its effects decrease with increasing age of the plant and tissue.

Fluorides

Sources:

1.combustion of coal;

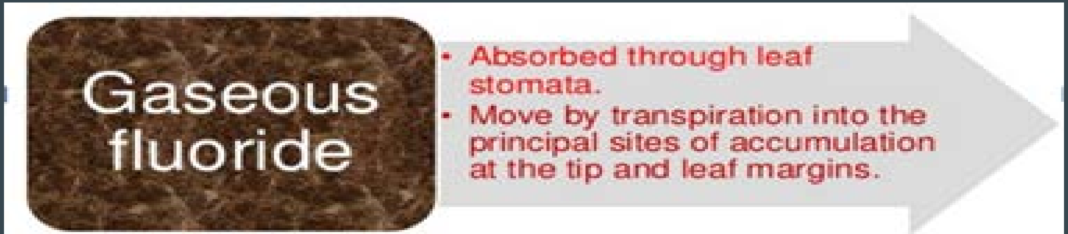
2.production of brick, tile, ceramics, and glass;

3.manufacture of aluminium and steel;

4.production of hydrofluoric acid, phosphate chemicals and fertilizers.

Why Fluorides can impact rice yields ?

Mechanism:



Fluorides combine with metal components of proteins and thus interfere with the activity of many enzymes, chlorophyll and cellulose synthesis are inhibited.

As a result, the cell wall composition, photosynthesis, respiration, carbohydrate synthesis, synthesis of nucleic acids and nucleotides and energy balance of the cell are affected.

Symptoms:

1. Acute symptoms of tip necrosis, occasionally with a reddish-brown band.
2. The chronic symptoms includes leaf yellowing and mottling.
3. Rice glumes were also affected, showing tip necrosis with dark brown band. If the glumes are severely affected, no grains will be formed. Dead tips of leaves and glumes become white or greyish white.

Effect:

Fluoride affects almost all the biochemical and physiological process of the plant and causes serious damage to the plant.

These effects ultimately lead to the reduction in yield.

Aerosols

Direct Effects

Reduction in total solar radiation

Aerosol impact on the direct and the scattered radiation

Settling of aerosols on the leaves

impact of the acidity of the haze

Indirect Effect

Impact of the haze on the hydrological cycle

Change in surface temperature from the haze

Aerosol affect on Solar Radiation

Solar Radiation (Indirect and Direct)

$$I_s^{tot}(\tau_a) = \int I_s(\lambda, \tau_a) d\lambda.$$

Aerosol: Absorbs and scatters solar light

Aerosol optical depth

$$I_s^{dir}(\lambda, \tau_a) = I_0(\lambda)\exp([-\tau_a(\lambda) + \tau_g(\lambda)]/\cos(\theta)),$$

Single scattering albedo

$$w_a(\lambda) = \sigma_{sp}(\lambda)/\sigma_{ep}(\lambda).$$

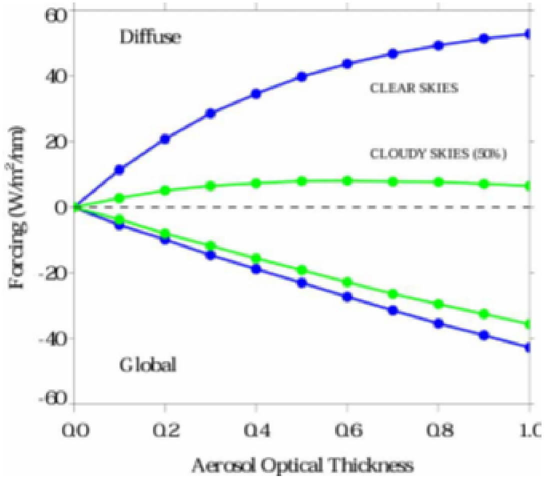


Figure 8.1: Aerosol effect on diffuse and global surface fluxes (direct aerosol forcing) in the PAR (Photosynthetically Active Radiation, 400-700 nm) spectral region. Calculations are made for the case of grassland using the INDOEX aerosol model (Satheesh et al., 1999; Podgorny et al., 2000).

How solar radiation effect crops

- Regulating carbon assimilation by plants by solar radiation
- Water loss to the atmosphere

Crop yield vs Solar Irradiance

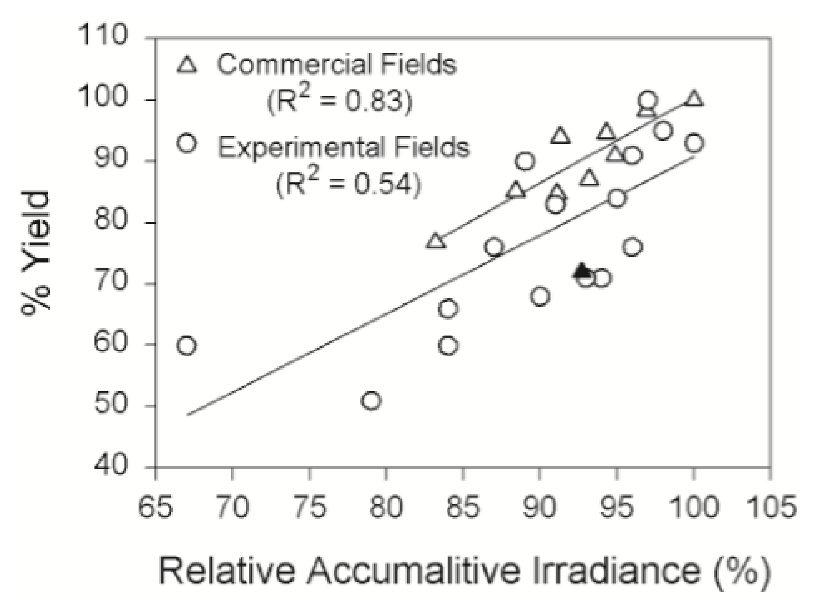


Fig. 5. Scatterplots of measured yields of rice cultivated in Texas as a function of accumulated surface solar irradiance received during a 40-day critical sunlight-

Chameide W.L. et al, PNAS, 1999

Rice and Wheat

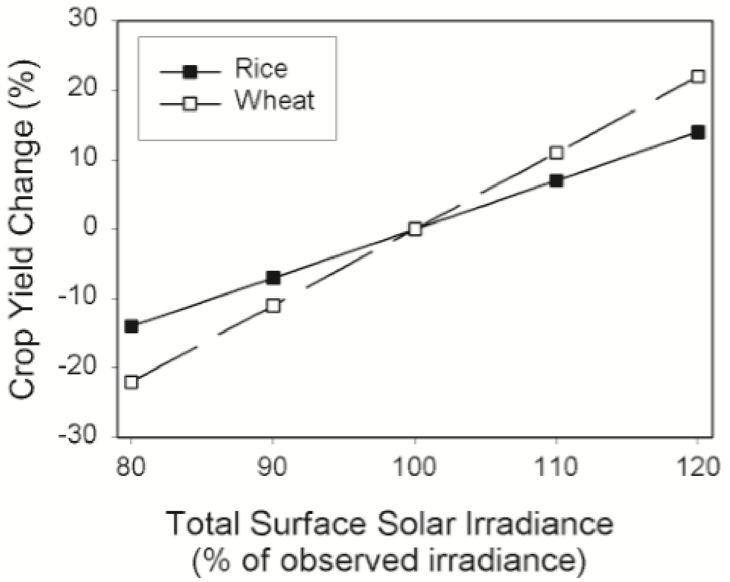


Fig. 6. Model-calculated percentage change in crop yields as a function of the assumed total surface solar irradiance, with 100% representing the observed irradiance. The calculations were carried out by using conditions appropriate for Nanjing (see Table 3).

Table 3. Crop model inputs and base results for wheat and rice yields in Nanjing

	Weather data*	Sow date	Harvest date	Mean yield for base model†, kg/ha
Wheat	1969–1979	November 9	June 8	4,053
Rice	1970–1979	May 10	September 25	12,138

*Input weather data consisted of averages of observations made during the indicated years. The data were obtained from Nanjing Agricultural Sciences (courtesy of Jin Zhiqiang).

†Base model represents the simulation using 100% of the observed total surface solar irradiance.

Chameide W.L. et al, PNAS, 1999

Winter Wheat

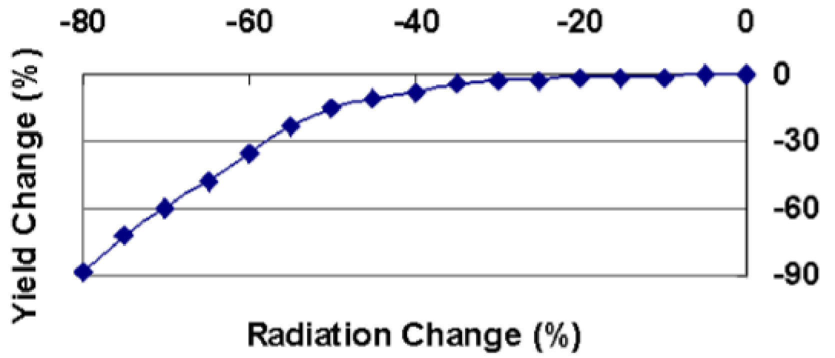


Figure 8.3: Winter wheat crop yield in New Delhi environment versus radiation change at the surface.

UNEP Assessment Report

Rice

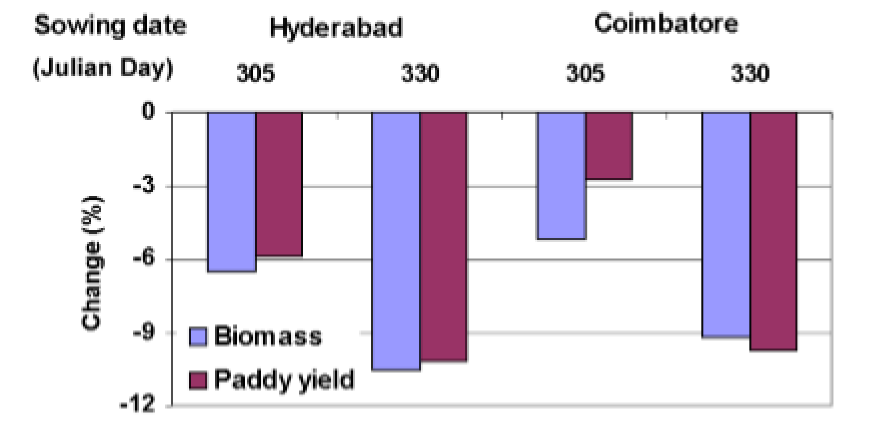


Figure 8.5: Percent change in biomass and yield of rice (rabi season) due to the direct effect of haze.

UNEP Assessment Report

Sugar cane

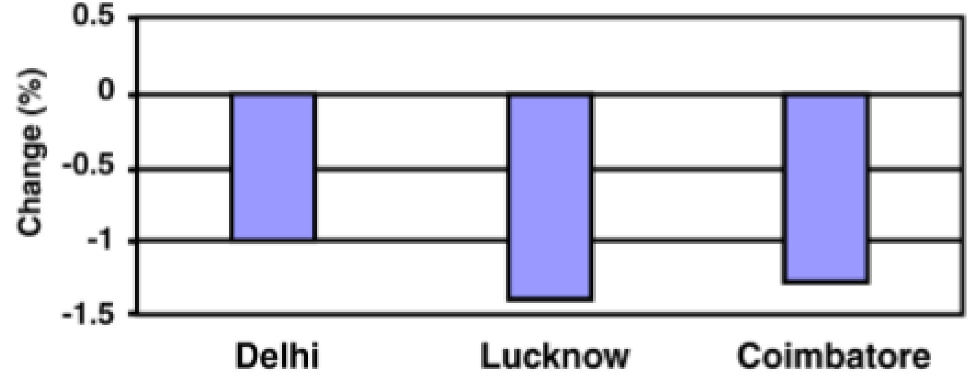


Figure 8.6: Percent change in cane yield.

UNEP Assessment Report

Rice

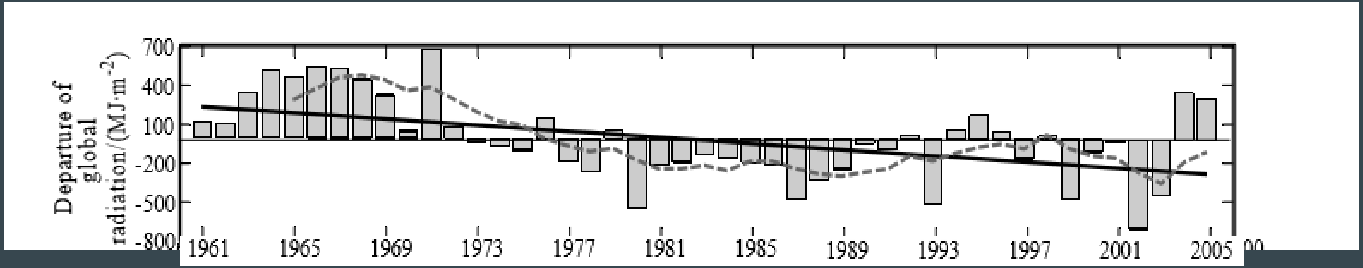


Table 2 Simulated rice photosynthesis, grain yield, ground biomass and total biomass change rate as daily radiation increased/decreased by 10% & 20% respectively compared with observations

Radiation changes (the whole growing season)	**+ 20%**	**+ 10%**	**0**	**- 10%**	**- 20%**
Change rate of photosynthesis (%)	+ 9.5%	+ 5%	0	- 5.4%	- 11.2%
Change rate of grain yield (%)	+ 9.2%	+ 4.8%	0	- 5.4%	- 10.9%
Change rate of ground biomass(%)	+ 8.6%	+ 4.4%	0	- 4.9%	-10.2%
Change rate of total biomass(%)	+ 9.1%	+ 4.7%	0	- 5.3%	- 10.8%

Soybean

$$NPP\left(grams\ C/m^2/s\right) = Photosynthesis - Respiration$$

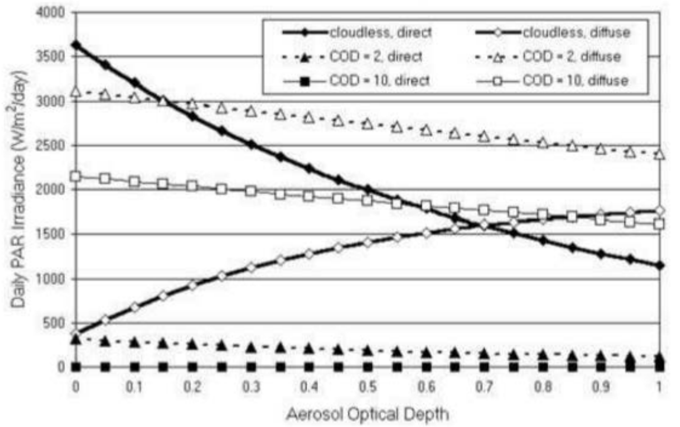


Figure 2. Integrated daily direct and diffuse PAR irradiance at 30°N on July 15 under various aerosol optical depths and cloudless sky, cloud optical depth 2, and cloud optical depth 10. Data are based on NCAR Tropospheric Ultraviolet and Visible Radiation Model calculations.

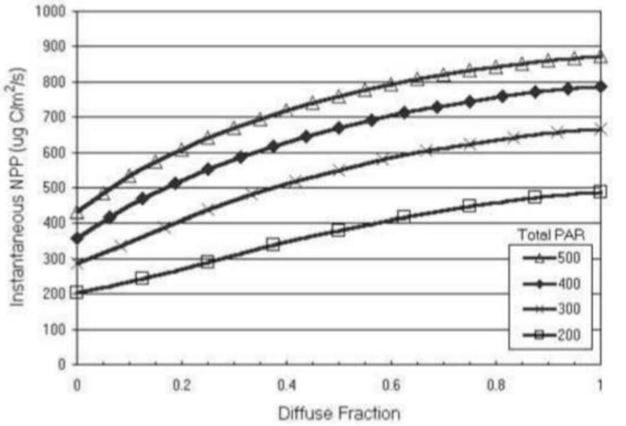


Figure 3. Instantaneous canopy NPP at various levels of total irradiance, as a function of the amount of irradiance that is diffuse. Data are based on Norman canopy model with the base case assumptions of Table 2 and a solar zenith angle of 45°.

Cohan D.S. Glob. Biochem. Cycle,2002

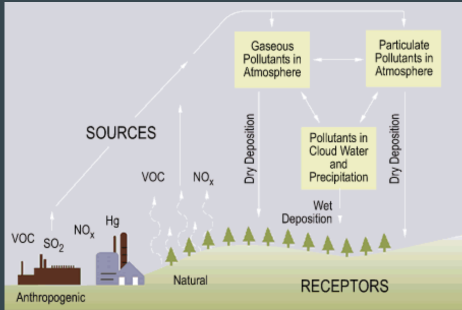
Acid Rain

Slower growth, injury, or even death of forests, by damaging leaves

Limiting nutrients available to trees

Exposing the trees to toxic substances slowly released from the soil

UNEP Assessment Report



Increased Temperature

Air Pollution & Increased Temperatures

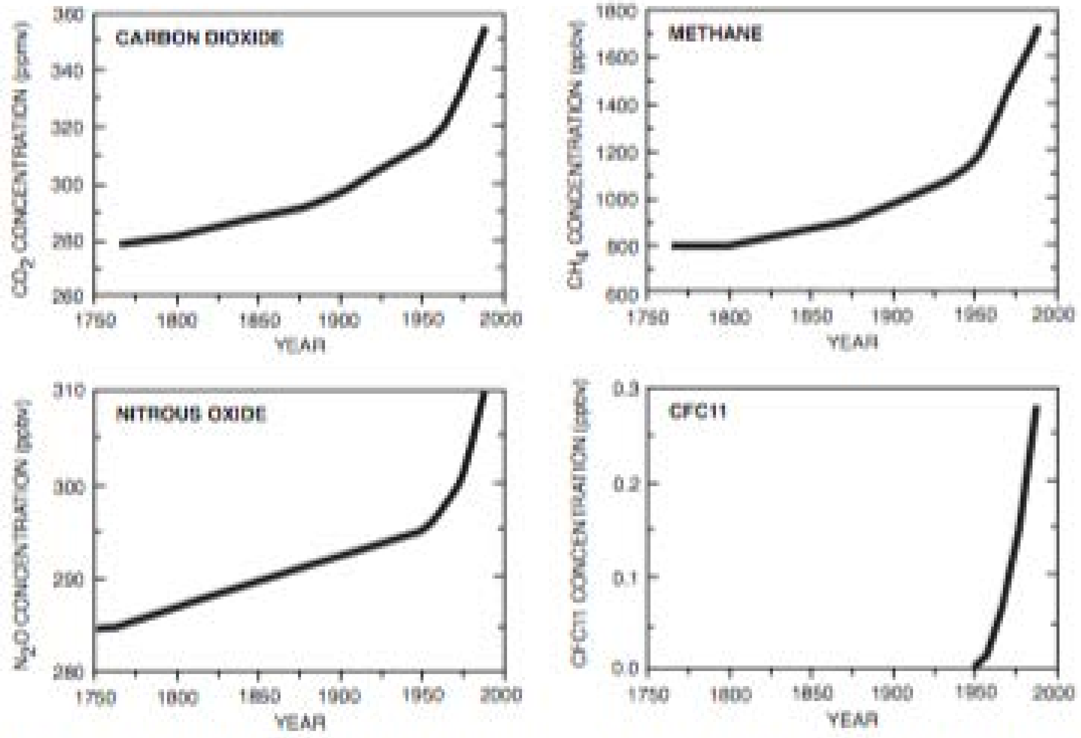
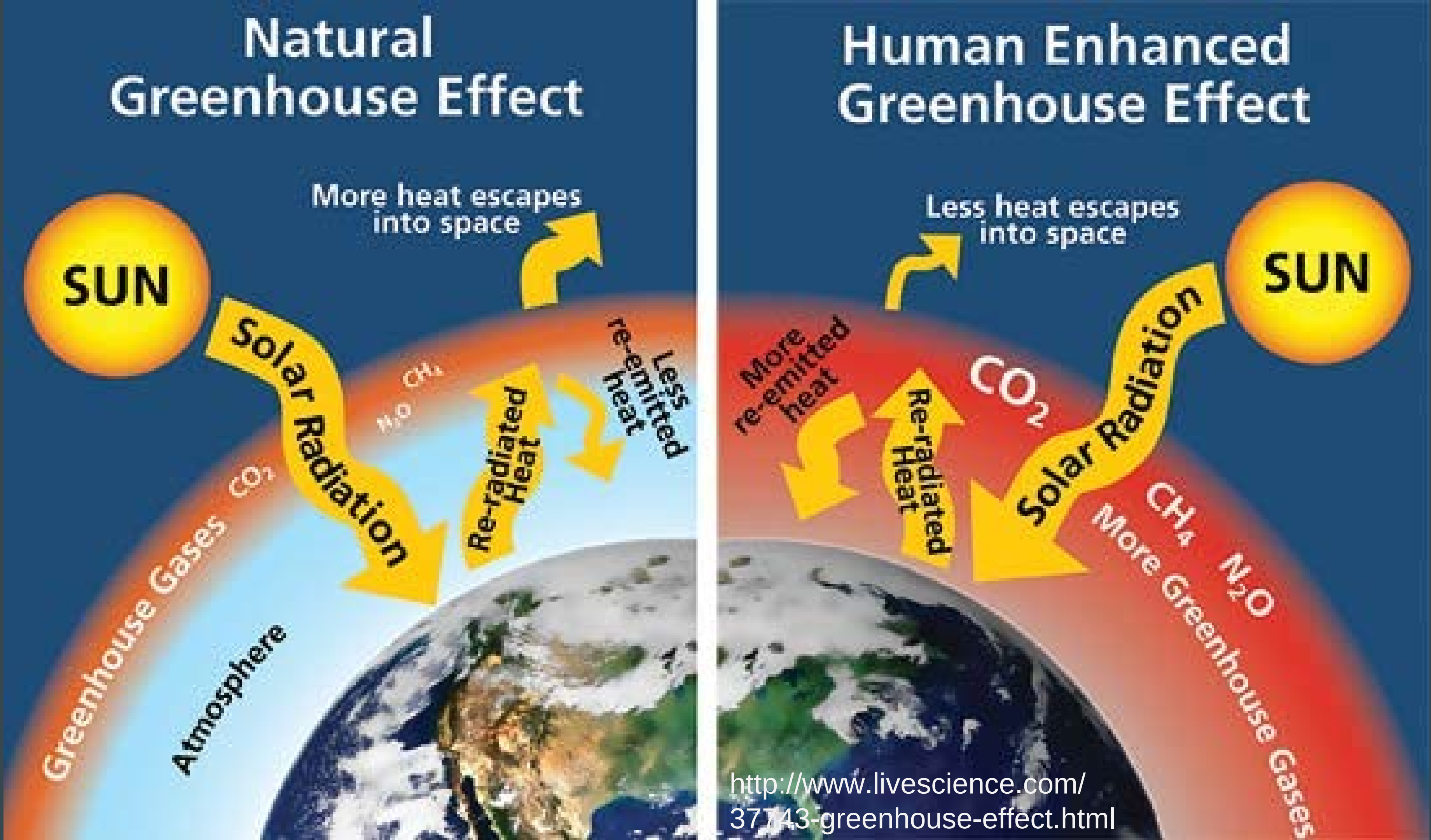


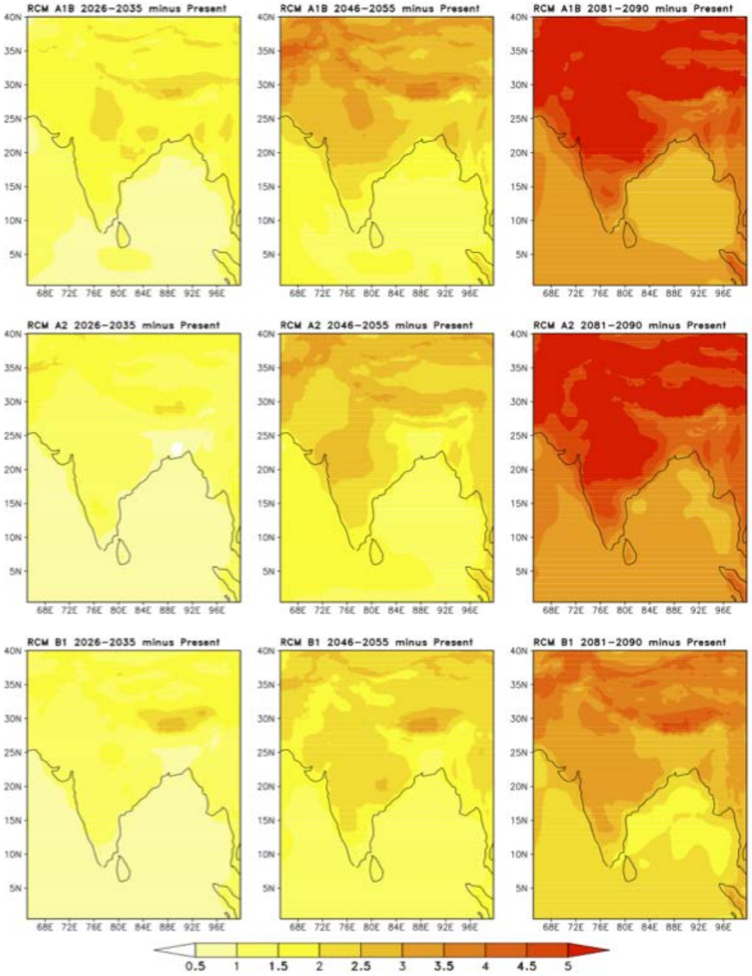
Figure 7-1 Rise in the concentrations of greenhouse gases since the 18th century

Jacob, 1999.



http://www.livescience.com/37743-greenhouse-effect.html

Figure 8: **Spatial Distribution of Projected Changes in Mean Surface Air Temperatures under Different Emission Scenarios** (top A1B, middle A2, and bottom B1) **for Three Future Periods in South Asia**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, RCM = regional climate model.

Predicted Temperature Changes in South Asia

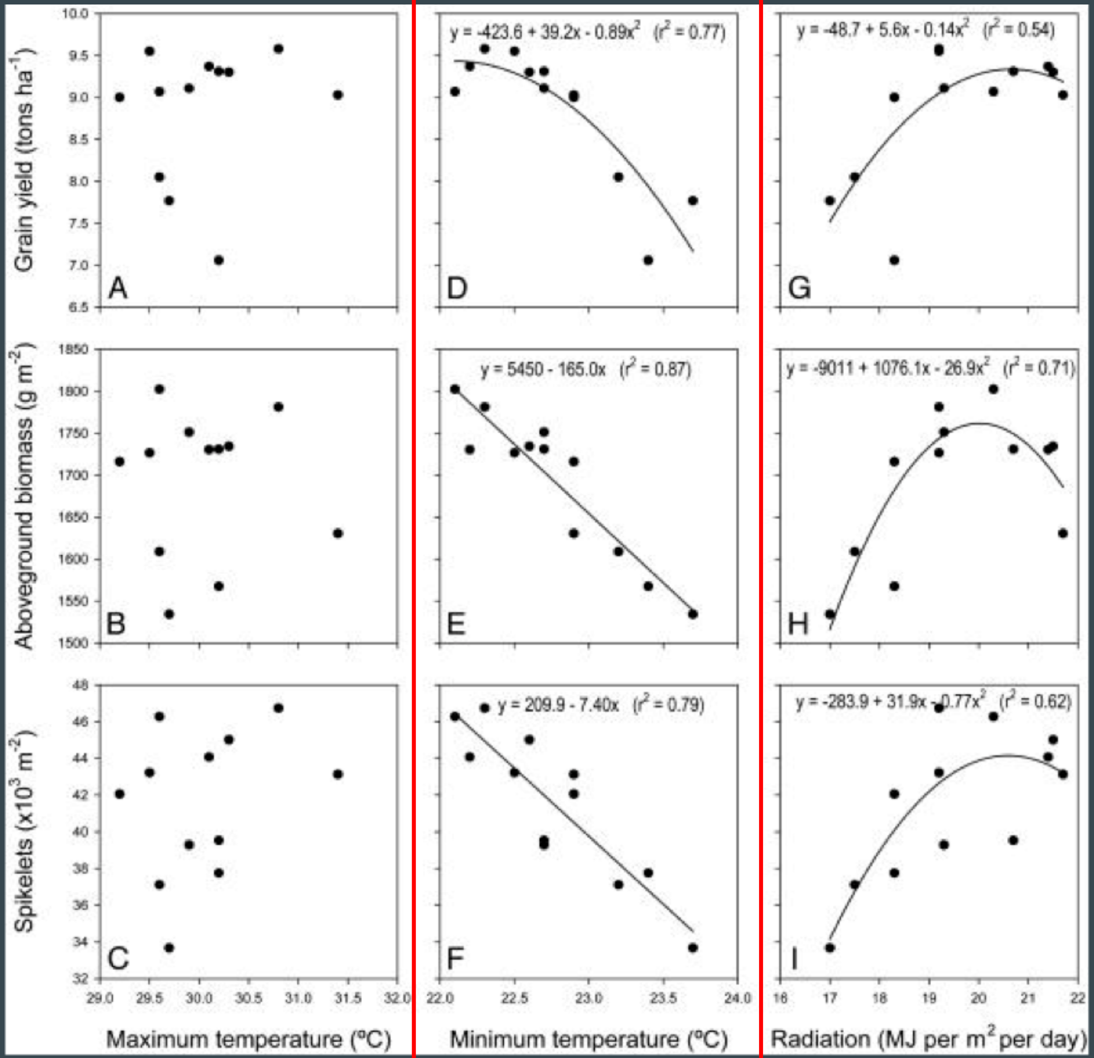
IPCC, Special Report: Emission Scenarios, 2007

Table 3: **Temperature Change (°C) in South Asian Countries for 2030, 2050, and 2080 from 2000 Baseline, under Different IPCC Emission Scenarios**

Country	2030			2050			2080		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Bangladesh	0.9	1.9	1.0	1.6	2.5	1.6	4.2	4.2	2.9
Bhutan	1.5	1.9	1.7	2.3	2.6	2.2	4.5	4.4	3.2
India*	0.6–1.8	0.9–2.4	0.7–2.0	1.3–2.9	1.4–3.5	1.1–2.6	3.0–5.6	2.8–6.2	1.9–3.7
Maldives	0.9	1.0	0.8	1.6	1.5	1.3	3.3	3.2	2.2
Nepal	1.6	2.0	1.7	2.5	2.9	2.3	4.8	5.0	3.4
Sri Lanka	1.0	1.1	1.0	1.8	1.5	1.3	3.6	3.3	2.3

* For India, range of temperature change is for 28 states and 3 union territories.

Increased Minimum Temperatures → Decreased Rice Yields



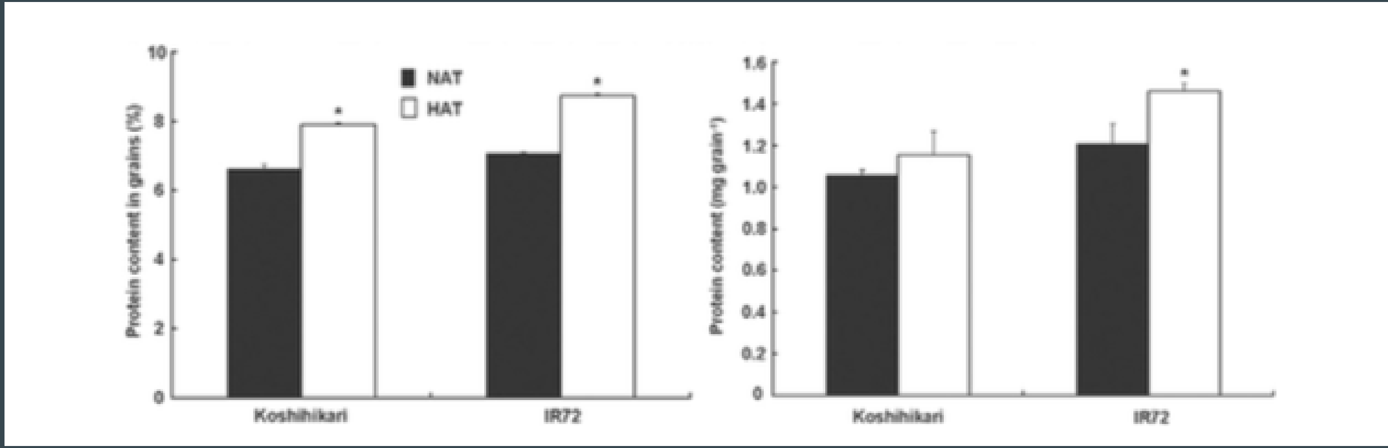
Peng et. al PNAS 2004

Temperature and Rice → Mechanism Unclear

Table 1. Effect of high air temperature (HAT) on microclimate of rice population in 2006 and 2007.

Year	Treatment	CO_2 conc.	Light intensity	Relative humidity
		μmol mol^{-1}	μmol m^{-2} s^{-1}	%
2006	NAT	350.1a†	1005.2a	72.5a
	HAT	349.3a	957.0a	72.1a
2007	NAT	349.6a	987.6a	74.0a
	HAT	348.8a	947.1a	73.6a

† Numbers within a column followed by the same letter for a year are not significantly different at $P = 0.05$.

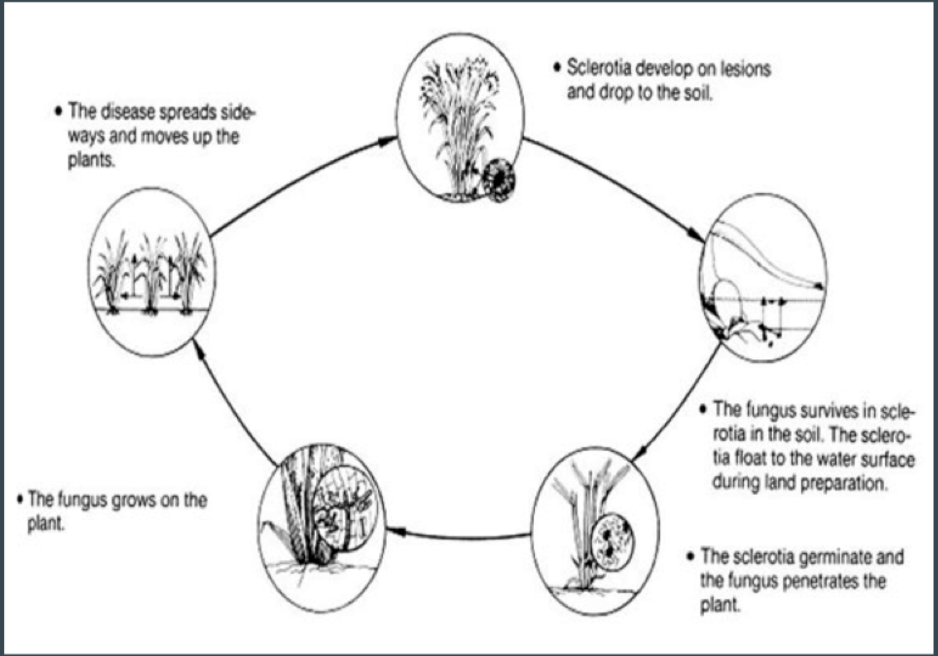


Liu, et. al, Agronomy, 2013.

Rice Pathogens

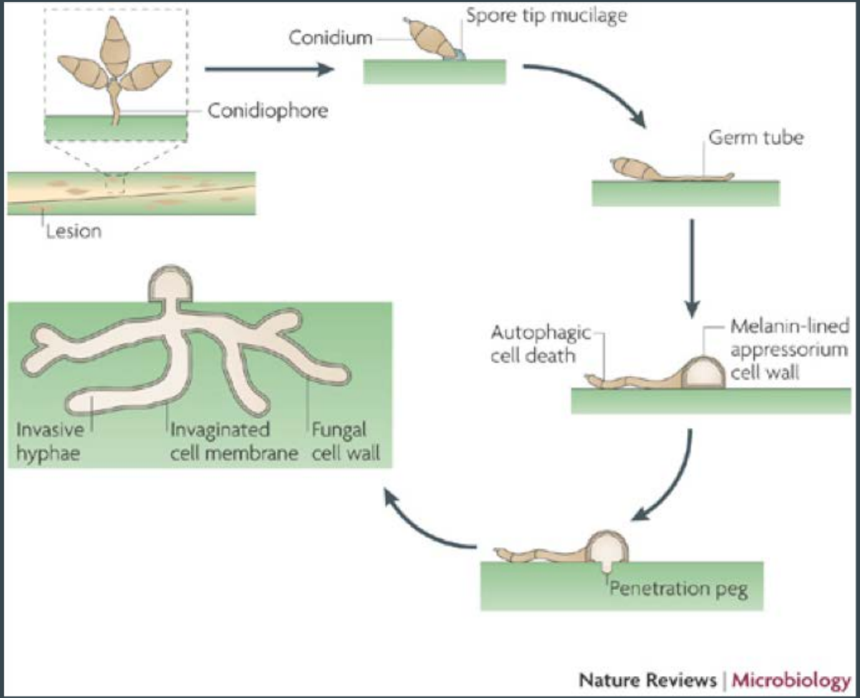
Major Rice Pathogens

Sheath Blight (Rhizoctonia solani)



http://agridr.in/tnauEAgri/eagri50/PATH272/lecture01/005.html

Rice Blast (*Magnaporthe oryzae*)



What factors?

-increased atmospheric CO_2

-heavy and unseasonal rains

-increased humidity

-drought

-cyclones and hurricanes

-warmer winter temperatures

J.Luck et. al, Plant Pathology 2011

Increased Temperatures and Pathogens

Temperature emerged as the primary determinant of plant pathogen incidence and severity (Luo Agric. & Forest Meteorology, 2015).

-Reduce Winter Kill → Increase Populations

-Increased number of reproductive generations per season (Cruz et al, 2007)

-Increased geographical range of pathogens (Dixon, 2012).

Kobayashi, et al, Phytopathology, 2006

Carbon Dioxide and Pathogens

Increased canopy size and density →
greater biomass with greater nutritional quality →
promotion of foliar disease such as mildews, leaf spots, and blights
(Coakley et al., 1999).

TABLE 3. Panicle blast incidence (%) under ambient and elevated CO_2 conditions

Year	Ambient	Elevated[a]
1998[b]	1.1	2.6*
1999[c]	23.9	20.3
2000	47.4	46.3

[a] Statistical differences between the $[CO_2]_a$ levels were determined with the paired t test within each year. Means followed by * are significant at $P <$ 0.05 between ambient and elevated conditions.
[b] Panicle blast incidence occurred naturally and was determined by estimating the disease severity through field observations on 15 September 1998.
[c] Rice plants were artificially inoculated on 9 August 1999 and 2000. The number of healthy and infected spikelets was counted for each plant. Disease incidence was determined by calculating the percentage of diseased spikelets.

TABLE 4. Sheath blight incidence and severity under ambient and elevated CO_2 concentrations in the field[a]

		Diseased plants (%)[d]		Lesion height (%)[e]	
Year[b]	N[c]	Ambient CO_2	Elevated CO_2	Ambient CO_2	Elevated CO_2
1999	High	3.2	10.1*	21.5	24.5
2000	High	20.1	40.3*	41.2	41.2
2000	Low	13.4	10.3	33.3	36.4

[a] Statistical differences between the $[CO_2]_a$ levels were determined with the paired t test within each year. Means followed by * are significant at $P <$ 0.05 between ambient and elevated conditions within each year and nitrogen (N) rate.
[b] Disease incidence and severity was assessed on 29 July 1999 and 10 August 2000 in the field.
[c] N was applied as ammonium sulfate at rates of 15 and 4 g/m^2 for high- and low-N subplots, respectively. Normal rate of N application was 8 g/m^2.
[d] Percentage of hills with more than one lesion.
[e] Height of the uppermost lesion above the soil surface relative to the plant height.

Carbon Dioxide and Pathogens

TABLE 3 - Effect of enriched CO_2 concentration on rice blast severity expressed by area under disease progress curve (AUDPC) in leaves of three rice cultivars (Agulha Precoce, Shao Tiao Tsao and Caloro)

		AUDPC		
Years	**Cultivars**	**C[1]**	**OTC-A**	**OTC+CO_2**
2007	Agulha Precoce	11.96c[2]	35.45b	71.13a
2008	Agulha Precoce	13.15a	15.67a	16.08a
	Shao Tiao Tsao	19.96a	27.71a	24.00a
	Caloro	25.62b	11.40b	72.15a
2009	Agulha Precoce	9.31b	9.60b	22.04a
	Shao Tiao Tsao	6.11ab	5.09b	7.17a
Means		14.35b	17.48b	35.43a

*C, control; OTC-A, open-top chambers with ambient CO_2; OTC+CO_2, OTC with elevated CO_2. [2]Means followed by the same letter in rows do not differ significantly (Tukey $p \leq 0.05$).

Goria et al, Trop. Plant Path. 2013

CO2 and Increased Plant Growth

De Costa et al., Field Crop Research, 2006

-grew rice under higher CO2 in Sri Lanka

-looking at rice specifically grown under temps >30 degrees C

-found an increase in grain yields

-increased biomass production overall

-increase in RUE (Radiation use efficiency)

-seed yields were 24% and 39% higher than ambient

Table 6.
Panicle growth rates (PGR) and overall crop growth rates (CGR) of rice grown under elevated (ca. 570 μmol mol^{-1}) and ambient CO_2 (ca. 370 μmol mol^{-1}) in open top chambers and in open field conditions in *Maha* (January to March) and *Yala* (May to August) seasons of 2001

Period (days after transplanting)	PGR (g m^{-2} d^{-1})			CGR (g m^{-2} d^{-1})		
	Elevated CO_2	Ambient CO_2	Open	Elevated CO_2	Ambient CO_2	Open
Maha						
38–54	10.3 a	7.4 b	10.5 a	37.6 a	30.1 b	40.2 a
54–67	40.6 a	23.9 b	19.3 b	79.3 a	26.5 b	5.9 c
67–94	12.7 a	16.9 a	15.4 a	−4.5 c	15.3 b	20.0 a
Yala						
40–53	4.9 a	4.8 a	4.6 a	20.7 a	18.3 a	20.7 a
53–60	9.0 a	10.3 a	13.44 a	12.9 b	32.5 a	29.4 a
60–70	13.2 b	5.0 c	22.8 a	16.1 b	25.4 a	29.2 a
70–94	26.7 a	12.5 b	8.7 c	24.9 a	9.0 b	−2.0 c

For each paramter, means connected horizontally by the same letter are not significantly different at $p = 0.05$.

Conclusion

As shown in our presentation, air quality will have direct, primary indirect, and possibly even secondary indirect effects on crop growth.

While we described several levels of effects in this presentation, there are many we omitted: extreme weather events, droughts, salinity infiltration, and more.

Major atmospheric pollutants, such as ozone, sulfur dioxide, NO_x and fluorides have significant impact on rice yields, especially, ozone can cause most of the damage.

All of these four pollutants have a common mechanism to reduce rice yields, that is inhibiting photosynthesis.

Aerosol affect crop productivity/yield by scattering and absorbing solar irradiation

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