Agricultural and Resource Economics
UPDATE
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS • UNIVERSITY OF CALIFORNIA
V. 10 no. 1 • Sept/Oct 2006

Is Dust "Busting" Crop Yields?

Maximilian Auffhammer

We have long known that air pollution has a negative effect on plant growth. Dust deposits on leaves and higher ozone concentrations in fields result in smaller plants for many crops. Recent research on local climate change has shown that a class of air pollutants, called "aerosols," may have a local drying and cooling effect. While cooler nights are good for many plants, these gains are possibly offset by decreased rainfall and solar radiation.

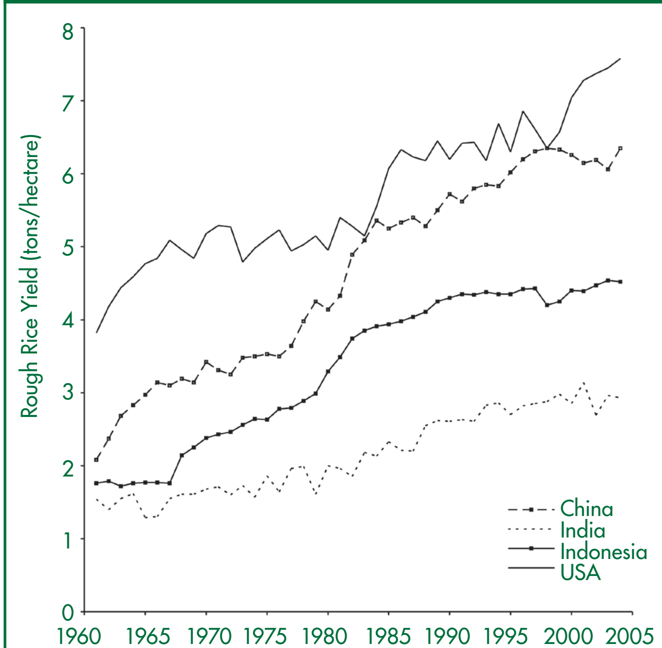
Rice is the staple food grain for over two billion people in Asia alone, who derive 60-70 percent of their caloric intake from the grain and its derivatives. It is also the most rapidly growing source of food in Africa. According to the United Nations Food and Agriculture Organization, rice production and processing employs over one billion people in the developing world alone. They identify declining yield growth rates, natural resource depletion, labor shortages, gender issues, institutional limitations, and environmental pollution as the main threats to global rice production.

As Figure 1 shows, yields in China, India, and Indonesia grew rapidly during the 1960s and 1970s. Most of this growth was due to the Green Revolution, which introduced hybrid varieties, irrigation, fertilizers, and pesticides to the developing country rice-production system. During the 1980s and continuing until present day, however, yield growth started to slow down and has recently leveled off. Explanations for the deceleration include sharply lower rice prices, deterioration of irrigation infrastructure, soil degradation due to the mismanagement of water and chemical inputs, stagnant technology on rain-fed farms, and reaching the technological frontier on irrigated farms. Ongoing work by UC researchers and their collaborators is examining the role of another possible culprit: air pollution.

The Asian Haze

Regional impacts of global warming hinge on the potentially sizeable cooling effect of a pollutant known as aerosols. These small particles, which measure about a millionth of a centimeter in diameter, reflect sunlight back into space and cause a local cooling effect at ground level.

Figure 1. U.S. and Asian Rice Yields 1960 2004



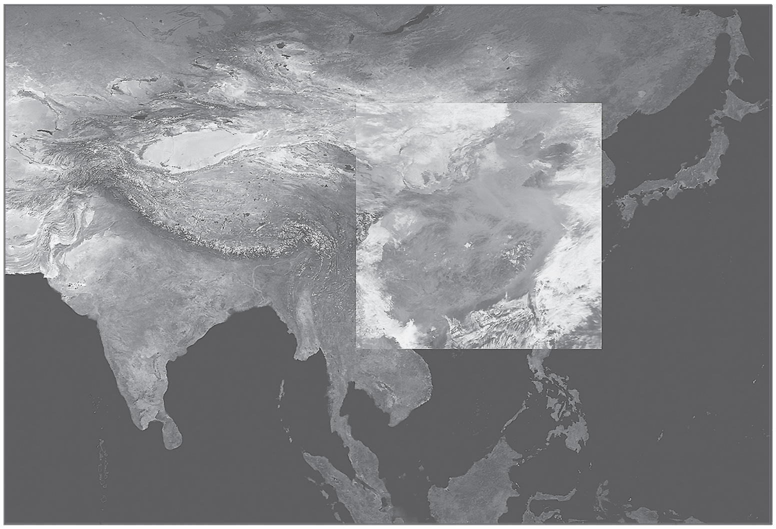
Source: IRRI World Rice Statistics (2006)

Also in this issue

ARE Faculty Profile: Aaron D. Smith 4

Retailer Pricing Practices for Fresh Avocados 5
Lan Li, Hoy F. Carman, and Richard J. Sexton

OECD Support for Agriculture: Has it Historically Harmed Poor Countries? 9
Alix Peterson Zwane and Margaret McMillan



Biomass burning and fossil fuel combustion are major sources of the haze.
Photo Credit: NASA

This class of pollutant is made up of various components, including sulfates, soot, organic carbon, and mineral dust. A large number of global warming models show that this cooling is one of the largest, if not the largest, source of uncertainty in predicting future climate at a regional scale. Field experiments, such as the Indian Ocean Experiment (INDOEX), have been undertaken to collect geographically specific data on the regional cooling effect of sulfates and other aerosols.

The INDOEX experiment led to the Atmospheric Brown Cloud (ABC) Project, chaired by UC San Diego Professor, V. Ramanathan, which is a multidisciplinary effort to study the aerosol layer known as the Indo-Asian haze, its impacts on local climate, and its socioeconomic consequences. The Indo-Asian haze covers most of South Asia and a substantial portion of the Indian Ocean from roughly November to May. Biomass burning and fossil fuel combustion are major sources of the haze. The region is home to much of the world's population and is experiencing rapid industrial and demographic growth. It is vulnerable to unexpected negative impacts from the haze on health, the hydrological cycle, and agriculture. Existing studies on the impacts of global climate change on Asian agriculture have taken into account the impact of warming on the hydrological cycle, water budget, and fertilization from additional CO_2. The predicted decrease in yields from warming, due to global climate change, averaged over the Asian region range from 15-30 percent by the year 2050. These studies have, however, not taken into account the potential direct and indirect impacts from the haze.

Impacts on Local Climate

The negative impacts of local air pollutants on human health have been extensively studied and have motivated regulation on a local, regional, national, and global level. The most widely discussed of these pollutants, ozone, also has direct negative impacts on plant growth. Laboratory experiments using open-top chambers have shown that 50 parts per billion (ppb) concentrations of ozone decrease yields of winter wheat by 10 percent and rice by eight percent. A doubling of this concentration, which is 20 ppb below the hourly federal standard set by U.S. Clean Air Act, leads to decreases of yields by 59 percent and 26 percent, respectively. Other pollutants which make up the haze, such as soot, dust, and fly ash, can settle on plant leaves and shield pollutants from solar radiation. These deposits interfere with the plant's ability to conduct photosynthesis and may cause localized warming on the plant. Further, through the acidity of the haze, it causes or augments negative consequences from acid rain on soil chemistry and plant tissues.

These direct effects of air pollution ignore the recently discovered interaction between the haze and local climate. In addition to the direct effects mentioned above, the haze can in theory affect agricultural production indirectly through three main pathways. The first is the reduction of sunlight available to crops. Aerosols increase the reflection of solar radiation back to space and, in addition, increase absorption of solar radiation in the atmosphere. The absorption and scattering of solar radiation lead to a large reduction of direct sunlight available to plants. The reduction of solar radiation due to the haze at the surface is estimated to be approximately 10 percent. The second indirect effect is the suppression of rainfall by haze. The presence of aerosols results in more clouds, which contain smaller droplets and are less likely to release rain. The cloud drops in turn further scatter solar radiation and cause additional dimming. The estimated rainfall reductions due to ABCs during monsoon season range from five to eight percent annually relative to the 1930-1960 average. The climate models further forecast an increased frequency of droughts. The final indirect effect of the haze is a local surface cooling, which is strongest during the months between October and May.

Estimating Impacts on Agriculture

There are numerous studies which attempt to estimate the impacts of changes in solar radiation, temperature, and rainfall on crop yields. Researchers either use data from experimental plots, where crops are grown under optimal conditions, and then artificially apply some stress to the plants—such as less solar radiation or water—to estimate impacts on yields. An alternate approach is to use computerized crop simulation models to estimate the impact of these stresses on yields and plant growth. For both methods, one attempts to apply all necessary inputs optimally and then increases or decreases the stress factor. While these models ignore the farmer's reaction to changes in environmental variables by switching crops or planting different varieties, they provide a first-order estimate of the impacts from environmental stresses.

A recent study published in the Proceedings of the National Academy of Sciences, estimates the impact on rice yields from changes in nighttime temperatures and solar radiation. Using weather and yield data from an experimental farm in Los Banos (Philippines) over the period 1979 to 2003, the authors show that a 1^0C increase in minimum temperature would result in a 10 percent decrease in grain yields during the growing season. Crop simulation studies have estimated a similar impact. Since aerosols cause a local cooling, this may seem like good news for irrigated agriculture. Unfortunately this may not be so. The same study shows a strong positive relationship between grain yield and solar radiation during low-radiation months, which is the case during monsoon season. Although the mechanisms are not yet well understood, a lower amount of solar radiation received by the plant during the grain-filling stage is one possible mechanism through which the haze may affect crop yields.

The immediate impact on irrigated rice yields through reductions in rainfall are likely small in the short run, since farmers can substitute by pumping more groundwater. For non-irrigated rice farming, the reductions in rainfall are likely to have larger consequences since farmers do not have this ability to substitute. This is a major concern for small subsistence farms.

The California Energy Commission has sponsored an ongoing research project, which attempts to quantify the impacts of anthropogenic aerosols on California climate. Preliminary results suggest a reduction in precipitation in the Sierra-Nevada Mountains and the Central Valley in February and August. Further, simulations suggest decreased ground temperatures and solar radiation in both months. The high concentrations of aerosols in many of the rural agricultural areas in the United States certainly warrant further examination of this phenomenon on crop yields in the U.S., which is a question currently under study at UC Berkeley's ARE department.

Los Angeles Haze Photo Credit: Ramanathan, 2003.

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For additional information, the author suggests the following sources:

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