

Pollution and its Consequences for Agricultural Productivity in Uttar Pradesh: A Review

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Abstract: *Uttar Pradesh occupies a central position in India's agricultural and environmental landscape. As the most populous state and one of the largest contributors to national food-grain production, Uttar Pradesh is often described as the "granary" of North India. The state lies at the heart of the Indo-Gangetic Plain, a region known for its high yielding wheat-rice systems, intensive irrigation, and dense population. This confluence of productive agriculture and demographic pressure, however, also makes Uttar Pradesh one of India's most pollution-stressed regions.*

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I. INTRODUCTION

Uttar Pradesh occupies a central position in India's agricultural and environmental landscape. As the most populous state and one of the largest contributors to national food-grain production, Uttar Pradesh is often described as the "granary" of North India. The state lies at the heart of the Indo-Gangetic Plain, a region known for its high-yielding wheat-rice systems, intensive irrigation, and dense population. This confluence of productive agriculture and demographic pressure, however, also makes Uttar Pradesh one of India's most pollution-stressed regions.

The state's agriculture is heavily dependent on wheat, rice, sugarcane, pulses, and oilseeds, many of which are grown in multiple cropping systems under canal and groundwater irrigation. At the same time, urbanization, industrialization, thermal power generation, transport, and biomass burning all contribute to high levels of air, water, and soil pollution. These pollutants do not remain confined to cities or industrial zones; they are transported by wind and water, infiltrating the agricultural landscape and affecting crop physiology, soil fertility, and water quality.

The central argument of this book is that pollution in Uttar Pradesh is not a peripheral environmental issue but a core structural constraint on crop yields. Air pollutants such as ground-level ozone, particulate matter, and dust reduce photosynthesis and grain formation; polluted irrigation water and agrochemical residues introduce toxicants and salinity into soils and plants; and land degradation in the form of waterlogging and salinity lowers the long-term productivity of irrigated landscapes. Together, these processes erode both current yields and the resilience of the agricultural system, with implications for food security, farm incomes, and rural livelihoods.

Understanding the effect of pollution on crop yields in Uttar Pradesh requires an interdisciplinary perspective that links agronomy, environmental science, hydrology, and policy. The aim of this book is to provide such a synthesis, reviewing the main pathways through which pollution affects crops, examining the evidence from Uttar Pradesh and the broader Indo-Gangetic Plain, and discussing strategies to reduce pollution-related yield losses while maintaining or enhancing food production.

II. AGRICULTURAL SETTING OF UTTAR PRADESH

2.1 Physical and agro-ecological context

Uttar Pradesh extends over approximately 2.4 lakh square kilometers and is dominated by the alluvial plains of the Ganga-Yamuna river system. These plains are formed from sediments deposited by rivers originating in the Himalayas, creating deep, fertile soils that are highly suitable for intensive agriculture. The state's topography is generally flat, with gentle slopes that facilitate canal irrigation and mechanized farming, but it also creates drainage challenges in low-lying areas.

Climatically, Uttar Pradesh falls under the humid subtropical zone, with a distinct monsoon season, a hot summer, and a relatively cool winter. The southwest monsoon brings the bulk of the annual rainfall, typically between June and September, while the winter months are generally dry but cool. This climatic pattern is well suited to the cultivation of both kharif (summer-monsoon) and rabi (winter) crops, allowing for multiple cropping and high cropping intensity across much of the state.

The state's agro-climatic regions are broadly divided into several zones, including the western plains, central plains, eastern plains, and the Terai belt along the Himalayan foothills. Each zone has slightly different rainfall patterns, soil types, and cropping systems, but the western and central plains are the most agriculturally intensive and are of particular relevance for pollution-related yield studies because they host the core wheat-rice belt.

2.2 Crop pattern and cropping systems

The dominant cropping pattern in Uttar Pradesh is the wheat-rice system, especially in the western and central parts of the state. In this system, rice is cultivated during the kharif (monsoon) season, followed by wheat in the rabi (winter) season, often with a short fallow or a short-duration crop such as pulses or vegetables in between. This pattern allows for high land use efficiency and is a key reason why Uttar Pradesh is such an important contributor to national food-grain output.

Wheat is the most important rabi crop in Uttar Pradesh, cultivated over millions of hectares and accounting for a large share of the state's total food-grain production. The state is one of the leading wheat producers in India, and its wheat surpluses are critical for the national public distribution system (PDS) and buffer stocks maintained by the Food Corporation of India (FCI). The wheat season typically runs from October–November sowing to March–April harvest, a period that coincides with some of the worst air quality in North India due to winter inversions and biomass burning.

Rice, in contrast, dominates the kharif season, with large areas in the eastern and central parts of Uttar Pradesh cultivated with high-yielding varieties under irrigated conditions. The rice-wheat system is highly productive but also resource-intensive, requiring substantial amounts of water, fertilizers, and other inputs. This intensification has raised productivity over the past few decades but has also increased the risk of environmental degradation and pollution-related yield stress.

In addition to wheat and rice, Uttar Pradesh is a major producer of sugarcane, pulses, oilseeds, and vegetables. Sugarcane is particularly important in western Uttar Pradesh, where the state hosts a large number of sugar mills and a well-developed processing industry. The cultivation of sugarcane is highly water-demanding and often associated with long-duration irrigation, which can exacerbate drainage and salinity problems in canal command areas.

2.3 Irrigation and groundwater dependence

Uttar Pradesh is one of the most heavily irrigated states in India, relying on a combination of surface irrigation (canals) and groundwater irrigation (tube-wells and wells). The state's canal network is extensive, drawing water from major rivers such as the Ganga, Yamuna, and their tributaries, and irrigating large tracts of the wheat-rice belt. Surface irrigation is particularly important in the central and eastern parts of the state, where canal systems provide the backbone of the irrigation infrastructure.

Groundwater, on the other hand, is the dominant source of irrigation in the western and central plains, where canal water is less available or unreliable. The state has a large number of tube-wells and shallow wells, many of which are operated by individual farmers or small irrigation cooperatives. This decentralized groundwater infrastructure has enabled farmers to intensify cropping and maintain high productivity, even in the face of climate variability, but it has also led to concerns about over-extraction and water-quality degradation.

State-level groundwater assessments indicate that Uttar Pradesh as a whole has a "safe" groundwater-availability status, meaning that total resources are within sustainable limits at the state scale. However, this aggregate picture masks significant local-level over-extraction, especially in the western and central plains, where groundwater levels have declined and some areas have moved from "safe" to "semi-critical" or "critical." In these regions, the cost of irrigation has increased, and the reliability of water supplies has decreased, adding another layer of stress on crop yields.

Heavy dependence on irrigation also means that crop yields are sensitive not only to the quantity of water but also to its quality. When rivers and canals are polluted by industrial effluents, urban wastewater, or agricultural runoff, or when

groundwater is contaminated by nitrates or other pollutants, the contaminants are often transferred directly to soils and plants, creating a hidden pathway for yield reduction. This link between water quality and crop productivity is especially important in Uttar Pradesh because of the state's high reliance on canal and groundwater irrigation for its staple crops.

III. AIR POLLUTION AND CROP YIELDS

Air pollution is one of the most significant and yet least visible factors affecting crop yields in Uttar Pradesh. The state's air quality is among the worst in India, with high levels of particulate matter (PM), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and ground-level ozone (O₃), particularly during the winter and early spring months. These pollutants are not confined to urban centers; they are transported by wind and can affect crops over large areas of the agricultural landscape.

This chapter focuses on three main aspects of air pollution relevant to crop yields in Uttar Pradesh: ground-level ozone, pollution from coal and industrial sources, and dust and particulate-mediated leaf injury.

3.1 Ground-level ozone and wheat

Ground-level ozone is a secondary pollutant formed when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react in the presence of sunlight. In Uttar Pradesh and the broader Indo-Gangetic Plain, this chemistry is driven by emissions from vehicles, thermal power plants, industries, and biomass burning, including crop residue burning in neighboring states such as Punjab and Haryana during the post-harvest period.

Ozone enters plant leaves through the stomata, the microscopic pores that regulate gas exchange. Inside the leaf, ozone generates reactive oxygen species that damage photosynthetic tissues, impair chlorophyll function, and accelerate senescence.[3][6] The net effect is a reduction in photosynthetic efficiency, lower biomass accumulation, and, in grain crops such as wheat, reduced grain number, grain weight, and final yield.

Wheat is particularly vulnerable to ozone because its critical reproductive phase occurs during the winter months, when ozone levels can be high due to complex meteorological and emission conditions. Several quantitative studies have attempted to estimate the impact of ozone on wheat yields in India and the Indo-Gangetic Plain. One national-scale assessment found that ambient ozone caused an average 14.18% reduction in wheat yields across India during 2008–2012, with the Indo-Gangetic Plain being the most affected region. Another more recent study focused on the Indo-Gangetic Plain estimated production-weighted wheat yield losses of 9.3% in 2019, 12.8% in 2020, and 11.3% in 2021, and explicitly identified Uttar Pradesh as the state with the highest ozone-related crop damage and also the highest ozone-attributed premature deaths.

These findings suggest that ozone is not a minor stress factor in Uttar Pradesh; it is a structural risk that affects millions of hectares of wheat cultivation and can significantly reduce both farm income and food availability. The implication is that efforts to improve wheat productivity in Uttar Pradesh cannot be separated from efforts to reduce ozone precursors such as NO_x and VOCs.

3.2 Pollution from coal and industrial sources

Coal-fired power plants and heavy industries are major sources of air pollution across North India, including Uttar Pradesh. Coal combustion releases a mixture of pollutants, including sulfur dioxide, nitrogen oxides, particulate matter, and heavy metals, all of which can affect plant physiology and crop yields. A recent India-wide study on coal-based electricity generation found that air pollution from coal-fired power plants can reduce rice and wheat yields by more than 10% annually in the most exposed regions. The study also showed that the spatial extent of yield loss can extend up to about 100 kilometers from the source, indicating that even villages located some distance from major power plants may still experience meaningful productivity declines. This long-range effect is due to the atmospheric transport of ozone precursors and particulate matter, which can travel large distances before affecting crops.

In Uttar Pradesh, this is particularly relevant because the state has a mix of large thermal power stations, industrial clusters, transport corridors, and densely cultivated farm land. Crop fields are often interspersed with or situated near industrial and peri-urban areas, creating a situation in which emissions from power plants and industries are not isolated but are integrated into the agricultural landscape.

The cumulative effect is that ozone-forming precursors, particulate matter, and other pollutants can reduce photosynthesis, increase stomatal closure, and accelerate plant senescence, leading to lower grain yields and poorer crop quality. Farmers may not perceive these effects directly because the damage occurs gradually and is often masked by other factors such as weather fluctuations or management practices, but the aggregate impact at the state level can be substantial.

3.3 Dust, particulate matter, and leaf injury

In addition to gaseous pollutants, particulate matter and dust deposition are important stressors for crops in Uttar Pradesh. Dust and fine particulates can settle on plant leaves, reduce light interception, interfere with stomatal function, and physically block gas exchange, all of which can lower photosynthetic rates and growth.

A field study conducted near a thermal power plant in Dadri, Uttar Pradesh, examined the impact of dust deposition on rice and wheat crops. The study found that dust accumulation on leaves was associated with reduced photosynthetic performance and measurable yield reductions, with paddy yields falling by about 11.6% and wheat yields by about 14.8% in the polluted environment compared to cleaner reference sites. The study also documented visible leaf injury, including chlorosis and necrotic spots, which are typical symptoms of particulate- and ozone-induced stress.

Although this study was localized, it provides a clear example of how air pollution near industrial and energy infrastructure can translate into tangible yield loss. In Dadri and similar industrial-peripheral zones, farmers may observe lower crop vigor, fewer tillers, reduced grain filling, or higher susceptibility to disease, all of which contribute cumulatively to lower productivity.

Across Uttar Pradesh, such conditions are not limited to single power plants. Many towns and cities are expanding rapidly, roads are being widened, construction activity is increasing, and traffic density is rising, all of which contribute to higher levels of particulate matter and dust in the air. This broad dispersion of particulate pollution means that even areas without major industrial facilities may still be exposed to some degree of dust-related stress on crops.

Moreover, during the winter months, low wind speeds and temperature inversions can trap pollutants close to the ground, leading to prolonged periods of high PM and dust concentrations over croplands. For crops such as wheat, which are in their critical reproductive phase during this period, such exposure can be especially damaging to yield-forming traits such as spike formation, grain number, and grain weight.

IV. WATER POLLUTION AND IRRIGATION-RELATED YIELD LOSS

Water pollution is a less visible but equally important factor affecting crop yields in Uttar Pradesh. The state's agriculture is heavily dependent on irrigation, and when the water used for irrigation is contaminated, the pollutants are transferred into soils and plants, leading to both direct and indirect yield reductions.

4.1 Industrial water pollution and surface water quality

Industrial activity in Uttar Pradesh includes tanneries, paper mills, textiles, chemicals, and small-scale manufacturing units, many of which discharge effluents into rivers, canals, drains, and groundwater bodies. These effluents can contain a range of pollutants, including heavy metals, organic chemicals, nutrients, and suspended solids, which can degrade water quality and affect agricultural productivity.

A recent India-wide study on industrial water pollution found that industrial activity significantly increases surface water pollution around emitting sites. The study estimated that crop yields in villages closer to polluting industries are about 10% lower than those in less-exposed villages, especially where farmers rely on canals or nearby rivers for irrigation. This yield reduction is attributed to the combined effects of direct toxicity to plants, changes in soil chemistry, and reduced irrigation efficiency.

This finding is highly relevant to Uttar Pradesh because the state's canal system is extensive and many agricultural areas are directly linked to river-fed canals. In districts where irrigation water is drawn from polluted rivers or canals affected by industrial discharge, crops may be exposed to toxic substances, which can reduce root growth, impair nutrient uptake, and lower overall yield.

In some cases, the impact may be visible in the form of leaf chlorosis, stunted growth, or poor grain filling; in other cases, it may be more subtle, appearing as reduced yield stability or lower crop quality over time. Either way, the effect is a chronic erosion of productivity that is not easily attributable to any single management factor.

4.2 Groundwater contamination and quality issues

Groundwater is another major source of irrigation in Uttar Pradesh, but its quality is increasingly under pressure from both industrial pollution and agricultural practices. In some regions, groundwater has been found to contain elevated levels of nitrates, heavy metals, or other contaminants, especially in areas with intensive agriculture and poor waste-management infrastructure.

High nitrate concentrations in irrigation water can affect crop physiology and soil microbial activity, and in extreme cases can lead to nitrate toxicity in plants or accumulation of nitrates in edible parts such as grains or vegetables. While such cases are more common in localized pockets, they indicate that groundwater-based irrigation is not immune to pollution-related risks.

In addition to chemical contamination, groundwater quality is also affected by salinity and sodicity, which are closely linked to poor drainage and waterlogging in canal command areas.

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