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ATMOSPHERIC POLLUTION AND CROP PRODUCTIVITY

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ABSTRACT

Atmospheric pollution is a growing threat to agricultural productivity and global food security. Pollutants such as ozone (O_3), nitrogen oxides (NO_x), sulfur dioxide (SO_2), ammonia (NH_3), volatile organic compounds (VOCs), and particulate matter impair crop growth by reducing photosynthesis, disrupting nutrient uptake, inducing oxidative stress, and lowering yields. Ozone is the most damaging pollutant, especially for cereals. Advances in remote sensing and crop modelling have enhanced monitoring, while sustainable mitigation requires emission control, climate–air quality integration, and pollution-resilient farming practices to protect crop productivity.

KEYWORDS: Air pollution, climate change, crop yield, food security, ozone, particulate matter

INTRODUCTION

Global food demand is expected to increase by 60–110% by 2050 due to population growth and urbanization. Simultaneously, atmospheric pollution continues to intensify, threatening agricultural productivity and food quality. Evidence from many regions indicates that air pollutants significantly reduce crop yields and generate substantial economic losses. Besides affecting plant growth directly, pollution modifies soil properties, climatic conditions, and ecosystem functioning. Understanding pollution impacts on crops is therefore essential for sustainable agricultural development and food security.

MAJOR ATMOSPHERIC POLLUTANTS AFFECTING CROPS

1. *Ozone (O_3):* Ground-level ozone is the most harmful atmospheric pollutant for crops. It enters leaves through stomata and generates reactive oxygen species (ROS), causing oxidative damage to cellular structures. Elevated ozone reduces photosynthesis, accelerates leaf senescence, impairs grain filling, and decreases crop yield. Wheat, rice, soybean, and many horticultural crops are particularly sensitive.

2. *Nitrogen Oxides (NO_x) and Sulfur Dioxide (SO_2):* Nitrogen oxides originate mainly from fossil fuel combustion and fertilizer-related emissions, while sulfur dioxide is released from sulfur-containing fuels. Excess nitrogen deposition may disturb nutrient balance and plant metabolism. Sulfur dioxide contributes to acid deposition and atmospheric haze, negatively influencing crop growth and quality.
3. *Volatile Organic Compounds (VOCs) and Ammonia (NH_3):* VOCs participate in photochemical ozone formation and influence plant physiological processes. Ammonia deposition alters nutrient availability and can suppress photosynthate production. Although their impacts are less studied than ozone, both pollutants significantly affect crop productivity and ecosystem functioning.
4. *Particulate Matter ($PM_{2.5}$ and PM_{10}):*Particulate matter originates from industrial emissions, transportation, biomass burning, and dust storms. Fine particles reduce solar radiation reaching crop canopies, interfere with photosynthesis, and may carry toxic substances. Dust deposition can either supply nutrients or cause toxicity depending on concentration and composition.

MECHANISMS OF POLLUTION-INDUCED YIELD LOSS

1. *Physiological Effects:* Atmospheric pollutants reduce photosynthetic activity, stomatal conductance, transpiration, and nutrient uptake. Ozone-induced oxidative stress damages chloroplasts and decreases carbon assimilation. Root growth and water absorption are also negatively affected.
2. *Biochemical and Molecular Responses:* Pollutants trigger ROS production, antioxidant enzyme activation, and changes in chlorophyll, proteins, and secondary metabolites. These responses often divert energy away from growth and yield formation. Long-term exposure can alter gene expression and increase susceptibility to diseases and environmental stresses.
3. *Indirect Effects Through Soil and Microclimate:* Pollution influences soil microbial communities, nutrient cycling, and mycorrhizal associations. Particulate deposition alters soil chemistry and moisture dynamics, while atmospheric haze modifies temperature and radiation regimes, indirectly affecting crop productivity.

CROP-SPECIFIC RESPONSES

1. *Cereal Crops:* Cereals such as wheat, rice, maize, and barley are among the most pollution-sensitive crops. Ozone exposure reduces grain yield, photosynthesis, and nitrogen-use efficiency. Rice has consistently been identified as one of the most vulnerable cereal species.

2. *Legumes and Oilseeds:* Soybean, common bean, canola, and safflower exhibit moderate sensitivity to atmospheric pollutants. Ozone may reduce seed size, protein content, and overall productivity. Information on many oilseed crops remains limited.
3. *Horticultural Crops:*Fruit trees, vegetables, and ornamental plants frequently exhibit visible injury even under ambient ozone concentrations. Yield reductions may exceed 50% in sensitive species. Pollutants also affect fruit quality, storage life, nutritional value, and marketability.

MONITORING AND MODELING APPROACHES

Ground-based monitoring networks provide valuable long-term observations of pollutant concentrations and crop responses. Remote sensing technologies enable regional assessment of pollution distribution and crop health through indicators such as leaf area index (LAI), gross primary productivity (GPP), and chlorophyll content. Advanced phenomics, hyperspectral sensing, and data assimilation techniques offer new opportunities for monitoring crop stress and improving pollution-impact assessments. Crop models increasingly incorporate pollutant effects to estimate future productivity under changing environmental conditions.

MANAGEMENT AND POLICY STRATEGIES

Mitigating pollution-related crop losses requires both technological and policy interventions. Key strategies include:

- Reducing emissions of ozone precursors and particulate matter.
- Improving fertilizer management to minimize NH_3 and NO_x emissions.
- Developing pollution-tolerant crop varieties.
- Enhancing soil health and nutrient management.
- Expanding air-quality monitoring in agricultural regions.
- Integrating climate-change adaptation with air-pollution control policies.

Climate–air quality co-management offers significant opportunities to protect crop productivity while improving environmental sustainability.

CONCLUSION

Atmospheric pollution is a growing challenge to agricultural productivity and global food security. Ozone, particulate matter, nitrogen oxides, sulfur dioxide, ammonia, and volatile organic compounds adversely affect crop growth through direct physiological damage and indirect changes in soil and environmental conditions. Cereals are particularly vulnerable, while horticultural crops often experience severe quality losses. Advances in monitoring, remote sensing, and modeling have improved understanding of pollution impacts; however, substantial knowledge gaps remain. Sustainable food production under future climatic and environmental conditions will require integrated approaches combining emission reduction, improved crop management, pollution-resistant cultivars, and coordinated climate–air quality policies.

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