IMPACT OF GROUND-LEVEL OZONE ON AGRICULTURE

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Ground-level ozone (O_3) is a major environmental pollutant that has garnered significant attention due to its detrimental impact on human health, ecosystems, and agricultural production. While stratospheric ozone forms a protective layer that shields the earth from harmful ultraviolet radiation, its presence at ground level is a different story altogether. Ground-level ozone, a secondary pollutant, is not directly emitted into the atmosphere but is formed through complex photochemical reactions involving nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. These reactions predominantly occur in urban and industrial regions where anthropogenic activities such as transportation, industrial emissions, and agricultural practices release precursors.

In addition to urban sources, agriculture contribute significantly to the formation and exacerbation of ground-level ozone. Agricultural practices such as use of synthetic fertilizers, livestock management, and farm machinery operation, release significant amounts of ammonia (NH_3), nitrogen oxides (NO_x), and VOCs into the atmosphere. These emissions not only contribute to local air pollution but can also lead to regional or even transboundary ozone formation. In rural and peri-urban areas, the combination of agricultural and urban emissions often results in higher ozone concentrations, which are further amplified by climatic conditions such as high temperatures and abundant sunlight that can promote the photochemical reactions that lead to ozone formation.

Ground-level ozone has far-reaching consequences for the environment, particularly in agricultural ecosystems. As a potent oxidative stressor, ozone enters plant leaves through stomata and interacts with cellular components, causing oxidative damage. This disruption impairs photosynthesis, reduces plant growth, and decreases crop yields. The visible symptoms of the damage include chlorosis, necrosis, and stippling on plant leaves; in severe cases stunted growth or premature senescence can occur. Crops affect most by ozone pollution include wheat, rice, soybeans, corn, and some other key staples in the global food production. Ground-level ozone impact not only the crop yield but also the nutritional quality of crop by lowering the levels of protein, vitamins, and minerals, thereby intensifying the concerns on food and nutritional security, particularly in developing countries.

In India, where agriculture have a crucial role in its economy and food security, the impact of ground-level ozone on crop production are becoming increasingly evident. Research indicates that substantial economic losses, particularly in the production of wheat and rice, because of ozone exposure. As ozone concentrations continue to rise due to local as well as regional emissions, it is essential to understand the full impact on agriculture and to develop strategies for mitigation.

GROUND-LEVEL OZONE AND CONTRIBUTORS

Ozone (O_3), composed of three oxygen atoms, is present in both the upper atmosphere and at ground level, with its location specific varying effects. In the stratosphere, ozone forms a protective shield against ultraviolet (UV) radiation. However, anthropogenic activities have led to the partial depletion of this beneficial layer, resulting in "ozone hole". In contrast, at ground level, ozone acts as a harmful air pollutant that affect both human and environment health, contributing to smog formation. Since the reactions that lead to the formation of ground-level ozone occur when pollutants from vehicles, power plants, industrial facilities, and refineries interact with sunlight, ozone concentrations are typically highest on hot, sunny days in urban areas. However, levels can also spike during cooler months. Moreover, wind can transport ozone over long distances, leading to elevated concentrations even in rural areas. Agriculture activities contribute significantly to the formation of ozone in multiple ways:

Emission of Ozone Precursors

- **Ammonia (NH_3):** NH_3 released from manure and synthetic fertilizers reacts with nitric and sulfuric acids in the atmosphere, indirectly contributing to ozone formation.
- **Nitrogen Oxides (NO_x):** Diesel-powered farm machineries and field burning of crop residues releases NO_x into the atmosphere.
- **Volatile Organic Compounds (VOCs):** VOCs emit naturally by some crops like corn, soybeans, and citrus, and due to the storage of livestock waste and manure.

Agricultural Practices Influencing Ozone Levels

- Use of some agricultural chemicals (pesticides and herbicides) release VOCs that contribute to ozone formation.
- Tillage and soil disturbance increases emissions of nitric oxide (NO) from soil, which contribute to ozone formation.
- Reduced soil moisture from poor irrigation raises temperatures and accelerate ozone formation.

REGIONAL AND SEASONAL VARIABILITY

Ozone levels in rural areas are often influenced by the pollutant transport from urban areas, which lead to have a cumulative effect of agricultural and urban emissions. Ozone formation is generally higher in summer due to increased sunlight and temperatures, which accelerate photochemical reactions.

IMPACT OF OZONE ON AGRICULTURE

1) **Reduced Crop Yields:** Ozone damages plant cells, disrupt photosynthesis, and affect the plant growth especially in vulnerable crops. The yield loss due ozone effect is estimated to be 5-15% globally, with localized losses up to 30%.

   Most Vulnerable Crops

   Highly Sensitive: Wheat, soybeans, potatoes, lettuce, tomatoes.

   Moderately Sensitive: Corn, rice, cotton.

   Less Sensitive: Barley, sorghum.

2) **Visible Leaf Damage:** Symptoms are chlorosis (yellowing), necrosis (cell death), stippling, and bronzing (Figure 1), which reduces the market value of fruits, vegetables, and ornamentals.

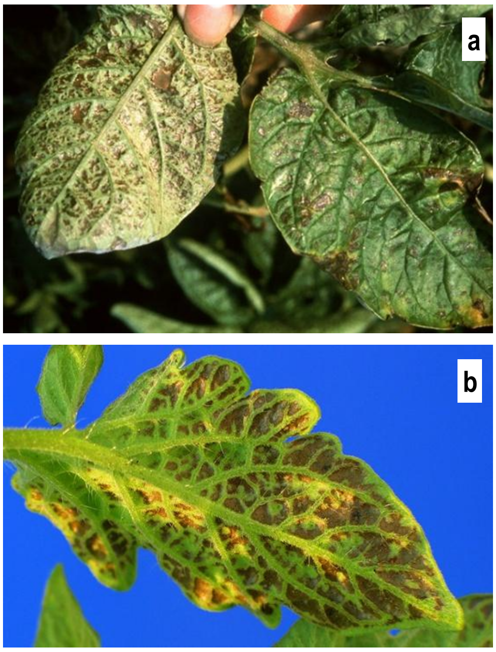

Figure 1. Ozone effect in (a) potato (b) tomato (Source:https://blogs.cornell.edu/livegpath/gallery/cucurbits/ozone-injury-in-cucurbit-crops/)

3) **Altered Plant Physiology:** Includes reduced photosynthetic efficiency, stunted growth due to energy diversion to stress responses, and decreased seed production and crop quality.

4) **Increased Susceptibility to Pests and Diseases:** Plants stressed by ozone are more susceptible to pests and fungal infections. Ozone can alter plant defensive mechanisms, making them more attractive to insects.

5) **Reduced Nutritional Quality:** Crops grown under high ozone levels may contain lower levels of protein, vitamins, starch, and flavonoids.

6) **Economic Impacts:** Financial losses from low crop yield and quality, increased investment on fertilizers, irrigation, and pest control to mitigate ozone damage amplify the global raise concerns over food security, especially in ozone-sensitive areas.

Table 1. summarizes studies on impact of ozone on Indian agriculture. Key findings include estimates of crop production losses (CPL) and economic damages associated with reduced crop yields. These studies highlight substantial regional variations, with the central and northern regions being the most affected. They underscore the need for targeted policy interventions.

Table 1. Scientific Research on Ground-Level Ozone and Agriculture in India

REFERENCE	OZONE EXPOSURE MATRICES	KEY FINDINGS
Sharma et al. (2019)	AOT40	Estimated ~$5 billion in wheat and $1.5 billion in rice losses using WRF-Chem model.
Lal et al. (2017)	AOT40 & M7	Annual wheat losses of 4.0–14.2 million tons (4.2–15.0%) and rice losses of 0.3–6.7 million tons (0.3–6.3%).
Sinha et al. (2015)	AOT40 & M7	Wheat losses: 20.8 ± 10.4 million tons; rice: 5.4 ± 1.2 million tons in Punjab & Haryana (2011–2013).
Ghude et al. (2014)	AOT40	Found wheat most affected (~3.5 ± 0.8 million tons lost), followed by rice (2.1 ± 0.8 million tons).
Debaje (2014)	AOT40 & M7	Economic losses for wheat: $1.2–4.1 billion USD; rice: $86–276 million USD (2002–2007).

MANAGEMENT STRATEGIES TO MITIGATE GROUND-LEVEL OZONE IMPACT

As ground-level ozone have substantial effects on crop yield, it is essential to minimize its impact through:

1) **Breeding and Selection**

- Development of crop varieties, screening of existing varieties for ozone-tolerance and their promotion in high-risk areas.
- Apply biotechnology to enhance plant stress tolerance.

2) **Soil and Crop Management**

- Soil health enhancement using organic amendments (e.g. compost, biochar).
- Maintain ideal soil moisture to reduce ozone uptake by plants.
- Practice conservation agriculture (reduced or zero tillage, crop rotation, cover crops)

3) **Irrigation and Nutrient Management**

- Optimize irrigation to keep stomata partially closed to reduce ozone uptake.
- Ensure balanced fertilization to make plants cope with oxidative stress.
- Adopt antioxidant sprays (e.g. ascorbic acid) to mitigate ozone damage.

4) Reducing Local Ozone Precursors

- Promote sustainable farm machinery use to reduce emissions of NO_x and VOCs.
- Ban or limit crop residue burning.
- Practice agroforestry to improve air quality.

5) Protective Measures for Crops

- Use physical barriers (e.g. greenhouse, shade nets) to reduce ozone exposure.
- Apply anti-ozone sprays (e.g. kaolin-based), antioxidants, and chemicals (e.g. ethylene diurea -EDU) to to enhance plant defense.

6) Policy and Community-Based Approaches

- Establish real-time air quality monitoring in farm fields.
- Strengthen regulations to reduce NO_x and VOC emissions at the regional level.
- Encourage rural and urban reforestation and educate farmers to adopt the best practices for managing ozone-related stress in crops.

CONCLUSION

Ground-level ozone (O_3) is a serious environmental stressor that impacts agriculture through yield decline, plant growth inhibition, and lowering nutritional quality. Agricultural activities contribute to ozone formation, worsening its effects on both urban and rural areas. Crops such as wheat, rice, and soybeans are especially vulnerable, posing risks to food security and livelihoods. Addressing this challenge requires a multi-faceted approach—ranging from breeding ozone-resistant crop varieties to implementing smarter farming practices and stricter environmental policies. A collaborative approach including farmers, scientists, and policymakers is vital to safeguard agriculture and ensure food security in the long run.

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