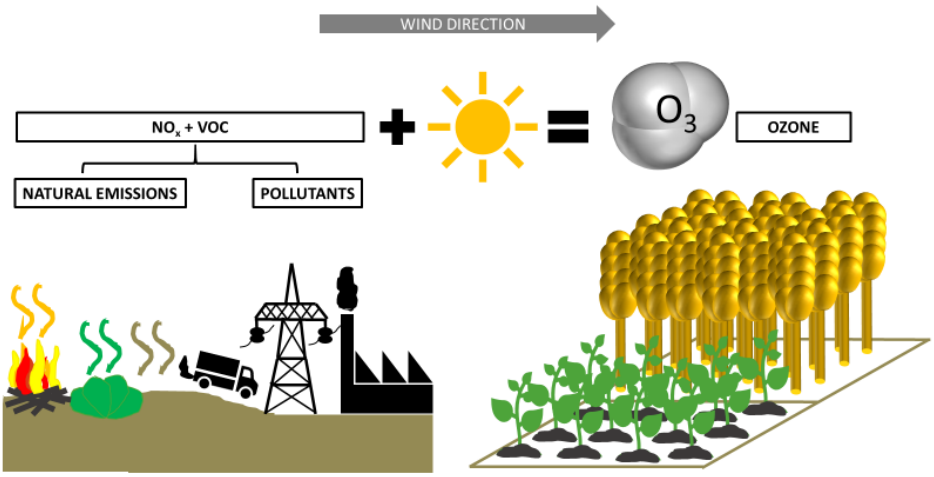
# Ground Level Ozone Pollution in South America: Effects on Tropical Crop Plants

## 1. *Background to the problem*

Ozone ($O_3$) is a gas that occurs naturally in the air. However, additional ground level ozone forms when pollutants from human activities react together in the presence of sunlight. Activities include vehicle use, industry and biomass burning. Ozone concentrations can be particularly high in agricultural areas downwind of large cities. Certain weather conditions (stable air mass, prolonged dry spells) and high levels of air pollution can lead to "ozone episodes." Episodes are when ozone concentrations peak for several days at a time. Ozone is a hidden threat when mixed with air because we cannot taste, smell, or see it.




**Panel 1**: The formation of ground level ozone from natural and pollutant emissions of nitrogen oxides and volatile organic compounds when they react with sunlight. Agricultural areas downwind of pollutant centres are at risk from ground level ozone pollution.

Ozone is taken in by plants through open pores on the leaf surface (known as "stomata"). Once inside the leaf, ozone reacts with the plant cell membranes, and together with the formation of some reactive by-products ("reactive oxidant species"), it can overwhelm natural plant defences. This then causes cell death and visible leaf injury. Visible injury allows us to *Recognize the problem* (see Section 3), and also compromises the value of leafy crops such as lettuce, amaranth and spinach.

Ozone is also an invisible problem. Even in the absence of visible injury, it can reduce yield through chronic effects, such as accelerated ageing. In wheat for example, leaves die back at an accelerated rate, while in common bean, leaves drop off earlier so the plants are smaller. Other chronic effects include altered above- below-ground biomass ratios, often with reduced root growth, and reduced rates of photosynthesis so that plants grow more slowly.

As well as being a threat to agriculture, ozone damages human health and materials, and contributes to climate change.

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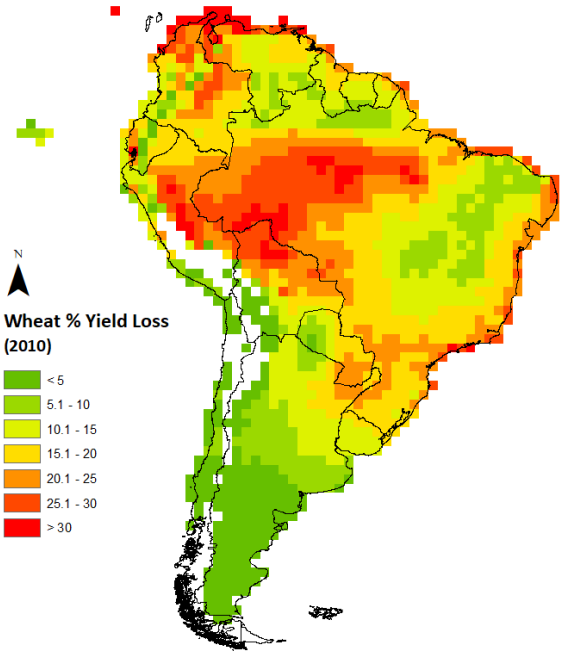
## 2. *Ozone in South America – and how it compares*

Globally, ozone concentrations have doubled since pre-industrial times (from 20 parts per billion (ppb) to 40 ppb). However, ozone concentrations vary across space and time.

There are few measurement stations in South America, so atmospheric chemistry models have been used to estimate ozone concentrations. These models predict moderate increases in the coming years as the pollutants that lead to ozone formation increase. However, long range transport of emissions from biomass burning (e.g. as forests are cleared, or grasslands are burned) can increase ozone concentrations downwind. These increased concentrations can damage certain crops (Panel 2).




**Panel 2**: Estimated percentage (%) loss of wheat yield in South America in 2010 due to $O_3$. Irrigated wheat tends to have higher yield, but is also more prone to ozone damage. Thus, there can be a much larger % yield loss of irrigated wheat compared to unirrigated wheat. Considering the proportion of irrigated and non-irrigated wheat per grid cell, this 'weighted by water source' map has been produced to show the average wheat yield loss across irrigation scenarios.

In some other regions (e.g. Asia), ozone already shows episodes of very high measured peaks (e.g. 150 ppb), especially eastern China and India. In contrast, episodic peaks have declined in Europe and North America but background levels continue to rise, related to climatic change and long-range transport of methane. As with the South American continent, the influence of ozone in Africa has mainly been modelled as the number of measurement stations is low. However, rising levels of other pollutants including from extensive biomass burning is expected to reduce crop yield in this region too. Only Australia and New Zealand are expected to have a low risk to agricultural productivity from ozone pollution.

It is important to note that exposure to high levels of ozone does not necessarily translate to damaging crop impacts. Ozone has to be taken into the plant for damaging effects to occur. This property gives us the opportunity for *Managing ozone pollution* (see Section 6).

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## 3. *Recognize the problem*

**Panel 3**: Ozone damage on a wheat leaf. Note the still visible veins.

Symptoms of ground level ozone pollution can vary slightly by crop species. There are several diagnostic features commonly found on ozone-damaged leaves:

1) Small yellow, white or bronze pinhead sized spots (known as "stipples") between the leaf veins.
2) Stipples can join together to cover large areas of the leaf when damage is severe. Large areas of dead cells ("necrosis") are called "flecks".
3) Damage appears primarily on the upper side of the leaf, but it can be seen on the underside in severe cases.
4) Older leaves tend to be more affected than younger leaves as ozone damage accumulates with time.

## 4. *Identifying the difference from other sources of damage*

Ozone damage can be mistaken for other kinds of leaf injury, for example mite infestation. However, if leaves are examined carefully (e.g. using a hand glass, or by zooming in to a photo on a phone) mites and white webbing can typically be seen on both sides of the leaf. Leaves can also be tapped while holding a paper underneath. Mites will fall off on to the paper. This won't happen with ozone injury.

Ozone damage does **NOT**:

1) Form haloes around leaf spots.
2) Cause concentric circles and small fruiting bodies inside the spots (in contrast to some fungal infections).
3) Rub off or wash from the leaf (in contrast to fungal infections and dust).

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## 5. *Variation in crop species sensitivity*

Crop species, and cultivars of the same species, vary in their sensitivity to ozone. This variation gives scope for *Managing ozone pollution* (see Section 6).

| Highly sensitive | Moderately sensitive |
|---|---|
| Beans and peas | Watermelon |
| Sweet potato | Tomato |
| Orange | Olive |
| Onion | Mustard |
| Lettuce | Oilseed rape |
| Wheat | Maize |
| Soybean | Rice |
| Tobaccco | Potato |
| Spinach | Grapes |

## 6. *Managing ozone pollution*

There are several actions that farmers can take to manage the threat posed by ozone in the immediate term.

1) **Timing irrigation** to avoid ozone episodes. High soil water leads to open leaf pores and increased ozone uptake. Avoid or reduce irrigation during the day when ozone concentrations are at their highest. Watering crops during the evening or night may avoid ozone issues while helping to avoid drought stress.
2) **Strategic reduction in irrigation**. For example, alternate wetting and drying, which induces moderate drought, has been found to increase rice yield while reducing the opening of leaf pores.

Short term management actions by farmers can be complemented by longer term strategies. Such steps will be helped by collaborations between farmers, crop breeders, crop scientists, and other researchers. These include:

1) **Changing crop species** or varieties to ones less sensitive to ozone where high ozone concentrations are known / likely to be a threat to production. Recent cultivars are sometimes more sensitive to ozone than older, 'heirloom' varieties. Crops with a shorter maturity period may reach harvest before ozone damage occurs.
2) **Developing new varieties** that are more resistant to ozone pollution, while accounting for other key stressors, such as heat and drought.
3) **Improving on-the-ground estimation of ozone pollution** and forecasting of when damaging ozone episodes are likely to occur, for instance through increasing the accuracy of local-scale weather forecasts. This will complement information for irrigation timing. Real


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time estimates of ozone (and other air pollutants) are available for South America here: https://aqicn.org/map/latinamerica/

In addition to managing the consequences of ozone pollution, action to reduce the emissions of pollutants that lead to the formation of ground level ozone pollution should occur. However, this requires policy intervention to be effective.

## *7. Want to know more?*

A video introduction to ozone can be found here:
https://www.youtube.com/watch?v=OBEJB-60jQU

You can also test your knowledge on ozone, and how to manage effects on crop plants at this quiz:
https://www.bspp.org.uk/ukceh-and-bspp-ozone-quiz-june-2021/

Don't hesitate to contact us using the e-mail or phone numbers below.

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