

Fine-tuning the ozone metric: unmasking errors in measuring wheat yield loss

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Even before the Industrial Revolution, when ambient levels of ozone were low, this pale bluish gas was associated with visible damage in several plants. Now, with a consistent rise in levels ozone is impacting agricultural yield.

Ozone is an unlikely pollutant. It is produced through secondary interactions¹. In the upper reaches of the atmosphere, ultraviolet (UV) rays interact with oxygen molecules to produce nascent oxygen molecules. These combine with other oxygen molecules to form ozone. Here, ozone acts like a shield and blocks the harmful UV rays from reaching the earth, an action that is vital to life.

Closer home, it is a different story. Ozone is produced by chemical reactions involving oxides of nitrogen and volatile organic compounds released by automobiles and industries. This tropospheric ozone can trigger health problems in humans and damage plants. Some of them, like wheat, are particularly vulnerable and are adversely affected by rising ozone levels.

Studies conducted in the past have projected that ozone toxicity will cause a massive drop in crop productivity. One of them even predicted that by 2030 losses in wheat production could be as high as 44.4% in South Asia^{2,3}.

‘These numbers could be highly conflated since they are based only on a single parameter – rising ozone concentration near agricultural land’, according to Shashi Bhushan Agrawal (Banaras Hindu University, Varanasi), a member of the team of researchers from the UK, India, China, Japan, the US, Germany and Sweden who have created a model to predict losses in wheat production due to ozone pollution more accurately⁴.

Research has shown that ozone-induced decline in crop growth depends on multiple factors like soil moisture, temperature, type of cultivar, wind speed and direction, irrigation strategies, presence of other pollutants and even carbon dioxide concentration in the region. In 2005, Long *et al.*⁵ (University of Illinois, USA) argued that free-air concentration enrichment studies do a better job of taking these parameters into account with-

out affecting the study sample. They grew plants in a large open area, either exposed to ambient ozone and carbon dioxide concentration, or in the presence of pre-industrial ozone-carbon dioxide levels, to assess the effects of ozone on crop productivity. They reported that previous studies had grossly overestimated the effects of ozone pollution.

Drawing upon this work, Agrawal and other researchers involved in the new study created a conceptually different model that can project loss in food grains due to ozone pollution. They reasoned that ozone will mediate its detrimental effects only when it enters the plant. This, in turn, is governed by the periodic opening of stomata, the tiny pores on leaves which help the plant exhale oxygen and inhale carbon dioxide. The CO₂ thus absorbed is used as raw material to produce all plant-based food. However, when ozone is present in the atmosphere, it could also secure entry through open stomata. Once inside, it can damage the plant in different ways.

Ozone is highly reactive. It has a tendency to produce oxygen radicals which are damaging to life forms – a property leveraged for killing microbes in water purification systems. Within the plant, these reactive radicals can interact with any molecule and alter its function. They may react with enzymes involved in photosynthesis and limit their activity. This could distort the process of energy production. Consequently, leaves start wilting and overall growth of the plant is affected.

When the damage is high, the fixed carbon is diverted from food storage towards repair pathways. This would affect grain size and quality, leading to losses in plant productivity, explains Agrawal.

Earlier measurements on yield loss were fraught with several issues. In earlier studies, scientists relied on mean concentration of ozone between 10:00 am to 5:00 pm for making crop loss estimation. However, there are certain crops which open their stomata only in the morning. In such cases, the projected damage would be inaccurate. Similarly, if the measurements are based on average

seasonal ozone levels and if the ozone peaks only during the afternoon when the stomata are closed, the projected damage will not be anywhere near the actual losses in crop yield.

Another problem with the earlier models is that they neglect the variations in plant physiology, the differences between various species and even between varieties of the same species. Since the associations assumed between ambient ozone concentration and crop yield were simplistic, even computer modelling rarely churned out accurate metrics for different regions. These metrics were also unsuitable for comparing the yield loss across different countries during different seasons.

Agrawal and his team proposed a more nuanced model for predicting losses in crop yield by accounting for the stomatal ozone conductance – the amount of ozone likely to enter the plant. The team used soil moisture indices and regional meteorological data to calculate the stomata conductance rate for each of the major wheat-growing regions of the world. Then, based on the history of wheat production, they projected the total wheat likely to be produced by each of these regions after correcting for losses that would accrue due to the current stomatal conductance rate.

The researchers found that estimations computed using stomatal ozone conductance projected lesser loss in wheat production than metrics based on ozone concentration. For instance, loss in productivity was earlier touted to range from 17.5% to 55% for prominent wheat-growing regions across the Indo-Gangetic Plains and Haryana based on rising ozone pollution. However, after factoring stomatal ozone conductance, the number reduced to less than 17.5%. No doubt, this is still a huge quantity. The model predicts that total loss in wheat production can amount to 85 million tones.

Wheat is an important food grain that meets 20% of the dietary protein requirement and calorie intake⁶. Thus, increased wheat production, plays an important role in the United Nations



Figure 1. Foliar injury symptoms observed across test cultivars in the form of small and large chlorotic spots, interveinal chlorosis, advanced chlorosis and necrotic areas.

Zero Hunger Programme⁷ launched in 2016, with the aim of ending world hunger by 2030. However, the strategies being implemented to increase wheat production have little or no contingencies in place to make up for the effects of ozone pollution.

One reason for this could be the gross overestimations projected by earlier models. Since several generic measurements based on ambient ozone concentrations did not pan out as projected, specialists and policymakers are yet to regard ozone pollution as an important parameter for designing agricultural policies.

However, the findings of the new study suggest anything but that. The authors point out that yield losses due to ozone may be ~8% of the current total wheat output. This is two units greater than losses caused by a rise in temperature (assumed to be ~6%). Yet only temperature remains an important parameter for strategizing maximum yield. Breeders are trying to choose temperature resistance as a favourable quality for new wheat cultivars.

‘But no such strategies have been employed for improving ozone resistance’, points out Aditya Abha Singh (Delhi University). His group recently published on this phenomenon where susceptibility to ozone has been compared among 14 Indian wheat cultivars⁸. These varieties were produced at different points in time over a period of 42 years between 1970 and 2012. To test the effect of ozone pol-

lution, researchers grew all the 14 cultivars either in the presence of ambient ozone levels or in the presence of exceeding levels of ozone, where the gas was pumped into a chosen study area for a period of five months (December–May). At the end of the cultivation period, researchers harvested the crops to analyse ozone-mediated damage in different varieties. Their study showed that all the species of wheat produced after 2000 were more susceptible to ozone toxicity.

Most countries are trying to boost wheat production by either increasing irrigation or by breeding wheat cultivars that have a higher rate of photosynthesis, according to Agrawal. Both these approaches boost plant growth by increasing carbon dioxide absorption through frequent stomatal opening. This should essentially increase food production. ‘But at the same time, increasing quantities of ozone entering the plant could derail the process of photosynthesis and negate the desired gains in crop productivity. Especially since the new crop cultivars are comparatively less resilient against ozone toxicity,’ Agrawal explains.

Scientists predict that under this scenario, irrigation will also do little to improve wheat production in the arid drylands of the northern hemisphere, where ozone levels are high. The irrigation-based boost in the stomatal opening may increase ozone toxicity (Figure 1). Similarly, crops being farmed in humid climate may also take a hit.

The obvious solution to this menace is to control the release of noxious gases that can lead to ozone production in the environment. However, till this is achieved, other measures could be used to circumvent the effects of ozone pollution. The model developed by Agrawal and his team could be used to choose the best irrigation practices for crops based on the physiology of the plant and weather conditions in the agricultural area.

Yet another solution will be to develop plant varieties that are resistant to ozone toxicity. This requires more knowledge on how ozone molecules are neutralized within plants. Once the scientists reveal the mechanisms responsible for ozone-resistance, they can be targeted to design ozone-resistant crops. Meanwhile, breeders should be encouraged to select ozone resistance as a desirable trait. Since certain older wheat cultivars have greater resistance to ozone, these could be improved for enhanced yield output and temperature resistance. However, these methods require farmers and government bodies to take note of ozone toxicity. Until then, low yield may be the norm.

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