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Impact of tropospheric ozone on plants and soil properties: A review

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Abstract

This review article elucidates the impact of tropospheric ozone on plants, crops, and soil properties. Exposure to ozone impacts growth, quality and productivity of plants. Ozone toxicity causes visible and physiological damage to the plant as well as change in soil properties. Visible injury is responsible for chlorosis, changes in pigmentation, and premature senescence of vegetation. Physiological injury causes reduction in photosynthesis, lowered carbon transport to the roots, enhance the turnover of antioxidant, enhance dark reaction, damage to reproductive processes, and reduce decomposition of early successional communities. Ozone exposure impacts stomatal conductance through cellular damage, specifically palisade mesophyll cells. Ozone toxicity also alters the timing and amount of carbon fluxes to the soils as well as emission of methane. Biotic and abiotic decomposition changes after its exposure in long-term.

Keyword: tropospheric ozone, nitrogen oxides, volatile organic compound, stomata, soil properties

Introduction

Ozone (O_3) which is three atoms of oxygen in combined form present throughout the atmosphere and can be good or bad depend, where it is found. The largest fraction of O_3 (90%) is found in the stratosphere (15-50 km from Earth's surface), which filters incoming UV-visible radiation (Colls, 1997) [8]. So, it is called good ozone. The ozone present in troposphere (0-15 km) is toxic pollutant, which impact climate, air quality, plants, human health, and soil properties. So, it has global importance (Ashmore, 2005) [3]. Tropospheric ozone also called bad ozone is produced by the photochemical reaction of CO, CH_4, and other hydrocarbons in the presence of nitrogen oxides (NOx) (Schlesinger *et al.*, 1991) [23].

$$NO_2+O_2 \rightleftharpoons NO+O_3 \quad (1)$$

$$CO+2O_2 \rightleftharpoons CO_2+O_3 \quad (2)$$

$$CH_4+4O_2 \rightarrow HCHO+H_2O+2O_3 \quad (3)$$

Equation (2) and (3) depends on reaction with OH and with NOx as they occur in equation (1).

Ozone is also destroyed through photochemical reaction of NO, HO_2 or OH. Primarily, NOx is produced by fossil fuel combustion (63%) and secondarily it is produced by bio-mass burning (14%), soils (11%), lightening (10%), and from other sources (IPCC, 2001). Fossil fuel combustion is also responsible for the emission of hydrocarbons. Hydrocarbon is also emitted from direct evaporation of fuel, use of solvent, manufacturing of chemicals and natural vegetation (Mauzerall and Wang, 2001) [16]. Another precursor of O_3 formation is volatile organic compound (VOCs), which is emitted from natural vegetation. The VOCs decomposed into peroxy radical (RO_2), which combine with NO to generate NO_2 (Krupa and Manning, 1988) [14].

During past decades, due to rapid development in the field of economy, the concentration tropospheric ozone is increased at an annual rate of 0.5% - 2% (Vingarzan, 2004) [27] and now it is reached up to 50 ppb globally (8- hourly average in summer) (Fowler *et al*, 2008) [10]. Tropospheric ozone is mainly originated in urban areas and transported into different region by local winds and also downward from the stratosphere (Oltmans and Levy, 1994) [18]. Elevated level of O_3 in rural and remote regions is due to agricultural crops and forests (Agrawal *et al*. 2005) [1]. Maximum ozone formation occurs during day times with high temperature and solar radiation with low wind speed (Mauzerall and Wang, 2001) [16]. But, it is produced naturally to reach higher concentration in early spring (Singh *et al*., 1978) [25]. Currently, it reached to maximum in summer due to increased emission of NOx and VOCs (Mauzerall and Wang, 2001) [16]. In an unpolluted air, background ozone concentration in between 20- 50 ppb (Seinfeld, 1989) [24], but it exceeds over 60 ppb due to stratospheric input (Lefohn *et al*., 2001) [15]. The concentration of ozone reached to 400 ppb in polluted regions (Seinfeld, 1989) [24].

Impact of ozone

Tropospheric ozone is so much toxic that it has both acute and chronic effects. An acute effect is symptomatic and chronic effect is responsible for changes in growth, quality and productivity (Ghunde *et al*, 2008). Its effect on plants was first identified in 1950s and now it is recognized as the most important air pollutant, which effects human health, vegetation, soil, and materials. In India, first report of O_3 injury is reported by Bambawale (1986) in crop plants of leaf spot disease of potato in Punjab. Their symptom is similar to that of ozone stipple of potato reported in the U.S.A. it has been predicted that global forest land become 50 % effected by O_3 which has concentration 60 ppb by 2100 (Percy *et al*., 2002) [20].

Impact on plants

The chronic exposure to low concentration of tropospheric ozone results in visible injury to plants e.g. chlorosis, changes in pigmentation, and premature senescence. Due to acute exposure to maximum O_3 level results in flecking and stippling (Krupa and Manning., 1988) [14]. For selected tree species like yellow poplar, loblolly pine, and white pine (Somers *et al*., 1998; Laughlin and Downing., 1996) [26, 17] visible injury is correlated with reduction in growth but for wide range of species including species discussed above correlation does not exist (Chappelka and Samuelson., 1998; Reich and Amundson., 1985) [7, 22].

Elevated levels of ozone changes the physiology of plants and are responsible to reduce photosynthesis, lowered carbon transport to roots, enhance the turnover of antoxidant, enhance dark respiration, and reduced decomposition of early successional communities (Percy et al., 2003) [19]. Due to ozone injury, reduced photosynthesis decreases the growth rate either in volume or biomass. Reich (1987) result shows that decrease in photosynthesis reduces the growth 3 % for conifers, 13 % for hardwoods, and 30 % for crops. The decrease in biomass is due to production of active oxygen molecules when it diffuses into plant cells. When ozone concentration increases progress ively then detrimental effect of plants increases and its effect are greater during grain filling in wheat (Feng *et al*., 2010) [9]. Elevated O_3 activate the Phenylpropenoid pathway, which cause the release of phenolic compound and thus alter the carbon portioning to defense processes (Booker *et al*., 1998). The ozone has also negative impact on stomatal conductance (Mauzerall and Wang, 2001) [16]. Ozone damage the cellular membrane specially palisade mesophyll cells when it enters through the stomata from atmosphere through diffusion.

Impact on soil properties

Ozone does not only impacts aboveground plants organs but it also alters the timing and amount of carbon fluxes to soils (Anderson, 2003) and emission of methane. Its exposure reduces land carbon sink because of reductions in plant/growth of tree, offsetting the positive effect due to increase in CO_2 concentrations. During summer of dry periods greater concentration of ozone causes reduction in carbon compounds to the root- soil compartment (Goirissen et al, 1994). It has been also reported that elevated ozone reduces the cPOM N (particulate organic matter nitrogen) by 15 % and increases the C:N ratio by 7 % (Hofmockel *et al*., 2011). After long term exposure of elevated CO_2 and O_3, not only change the biotic factor controlling decomposition, but also alter the abiotic decomposition, such as soil temperature, soil moisture, and soil aggregates formation. All these type of factors alternatively effect soil soil carbon and nutrient cycling.

Conclusion

Troposheric ozone is so much toxic that it has both acute and chronic effects on aboveground plants organs as well as soil properties. Its toxicity effects growth, quality and productivity. Toxicity to ozone has visible and physiological damage to the plants. Visible injury is responsible for chlorosis, changes in pigmentation, and premature senescence of vegetation. Visible injury may or may not be correlated with reduction of growth. Physiological injury leads to reduction in photosynthesis, lowered carbon transport to roots, enhance the turnover of antioxidant, enhance dark reaction, damage to reproductive processes and reduce decomposition of early successional communities. Exposure to ozone has negative impact on stomatal conductance by damaging cellular membrane, especially palisade mesophyll cells. Ozone toxicity also alters the timing and amount of carbon fluxes to soils as well as emission of methane. Its exposure reduces the land carbon sink and cPOM N (particulate organic matter nitrogen). Its long term exposure changes the biotic and abiotic decomposition.

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