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Review Article

Rising Nitrogen Dioxide (NO_2): A Growing Threat to Environment and Plant Health

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ABSTRACT

The atmospheric increase in nitrogen dioxide (NO_2) has greatly impacted plant growth and health, which have been mainly due to the burning of fossil fuels and agricultural practices. Although diatomic nitrogen N_2 constitutes more than 78% of atmospheric composition, it is less reactive and not absorbed directly by plants. Since human activity increases reactive nitrogen, NO_2 is one such highly reactive nitrogen species. NO_2 is significant in photochemical reactions due to its interesting physicochemical characteristics and a density that is 1.59 times denser than air. Under the influence of sunshine, it oscillates between NO and NO_2 to sustain photochemical equilibrium. Some major sources of NOx for developing countries are crop waste burning, industrial processes, vehicle emissions, and combustion of biomass. Such emissions deteriorate air quality. This is because they result in the formation of such secondary pollutants as aldehydes, methane, ozone, or O_3, and HNO_3. NO_2 is seasonal and weather sensitive; it is also man-affected. High concentration may even promote photosynthesis or an accelerated rate of plant growth from delivering greater availability of reactive nitrogen and enhancing protection in the plants against diseases, provided that molecular defense mechanisms apply. On the other hand, over-accumulation of NO_2 leads to the accumulation of nitrite, the formation of reactive oxygen species, acidification of cells, reduced nitrogen uptake, and acute leaf damage. NOx emissions also play a role in sudden climate changes.

Keywords: Nitrogen dioxide (NO_2), Plant Health, Fossil fuel combustion, Climate change, Pathogenic infection.

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INTRODUCTION

Nitrogen (N) is a very abundant element, comprising approximately 78% of the Earth's atmosphere, mostly in the form of diatomic nitrogen (N_2) gas. Although it is very abundant in the atmosphere, atmospheric N_2 is not readily available for uptake by plants or for metabolic purposes (Kumar et al., 2024). It is, therefore, inert. However, over the last few decades, there has been a substantial amount of reactive nitrogen that has been added to terrestrial ecosystems (AlShehhi and Welsch, 2023). The NOx encompasses reactive nitrogen species that includes all the other gases which include nitrous oxide (HNO_2), nitric acid (HNO_3), and a large group of highly reactive gases (Sheng and Zhu, 2019). Nitrous oxide (N_2O) is an important greenhouse gas present in the atmosphere with an average global concentration of about 0.3 parts per million. These, primarily anthropogenic activities consist of the combustion of fossil fuels and agricultural practices; whereas the major source for nitrogen dioxide (NO_2) and nitric oxide (NO) is combustion (which are harmful to the environment and human health) processes, Follett and Hatfield, 2001; Seng et al., 2021. Nitrogen dioxide (NO_2) has a density 1.59 times that of air and has a molecular weight of 46.01 g/mol, with melting and boiling points of -11.2°C and 21.15°C, respectively (Jarvis, 2010). The physicochemical properties of NO_2 underpin its role in atmospheric chemistry, influencing the formation of photochemical smog and acid rain, among other phenomena (Ruijun et al., 2023). The increasing levels of reactive nitrogen, particularly nitrogen dioxide (NO_2), exert considerable impacts on environmental conditions (Lorente et al., 2019). The presence of heightened NO_2 concentrations enhances the availability of nitrogen in a more reactive state, which can elevate photosynthetic rates, promote plant development, and augment overall plant health (Iskandaryan et al., 2022). This physiological response activates molecular defense mechanisms, thereby not only strengthening plants but also enhancing their resilience against pathogen attacks. Moreover, nitrogen dioxide (NO_2) affects climatic dynamics and atmospheric phenomena, subsequently affecting human health and air quality (Wei et al., 2019).

NITROGEN EMISSION AND ENVIRONMENTAL POLLUTION

The troposphere emits $NO_x = NO + NO_2$ as NO is emitted first and through subsequent oxidation, gives out NO_2. Through sun-light, this NO_2 gets photolyzed back to NO thereby forming a photochemical equilibrium that persists throughout the daytime period (Werner et al., 2013). In developing countries, NOx is mainly produced by combustion of biomass, crop wastes, and industrial fuels, besides natural lightning, soil microbial activity, and vehicle emissions (Richter and Burrows, 2002). The generation of secondary pollutants, including nitric acid (HNO_3), ozone (O_3), methane, and aldehydes, which are aggravating factors for problems in air quality and have a major environmental impact, is primarily due to the photochemical reactions between nitrogen dioxide (NO_2) and hydroxyl radicals (OH) (Kanaya et al., 2007). The concentration of NO_2 is said to change spatially and temporally and is also very sensitive to both variations in meteorology and seasonal and human actions variations, according to recent reviews by Colbeck et al. (2010).

It poses a great challenge to developing countries as they are facing rapid industrial growth, urban expansion, and deforestation simultaneously (Cheng et al., 2012). These emissions increase the environmental pressures at both the local and regional levels. Air quality is deteriorating, and public health is being affected. NO2 concentrations average 1.102±0.08×1015 molecules/cm2 with an annual growth rate of 3.29% in Pakistan (Haq et al., 2014). The levels of reactive nitrogen species are also enhanced with increased consumption of energy and the emission of vehicles (Zhou et al., 2012). NO2 also hinders the problems facing the regulation of air quality in developing regions (Yue et al., 2019). The power of atmospheric oxidative is mostly dependent on nitrogen oxides. According to the U.S. Clean Air Report, (2010), Understanding the causes, variation, and effects of NOx emissions is important to have effective mitigation strategies. In addition, coordination in government action to reduce the emission levels and encourage better practices is necessary (Saud et al., 2011).

By implication, a host of issues ranging from climate variability, health challenges to public health in developing countries to environmental degradation have been noticed with NOx emissions increasing levels in developing countries. This shall all be addressed with an integrated approach whereby technological innovations will be optimized, strong regulation systems taken into consideration and scientific knowledge on NOx chemistry along with its impact on the environment.

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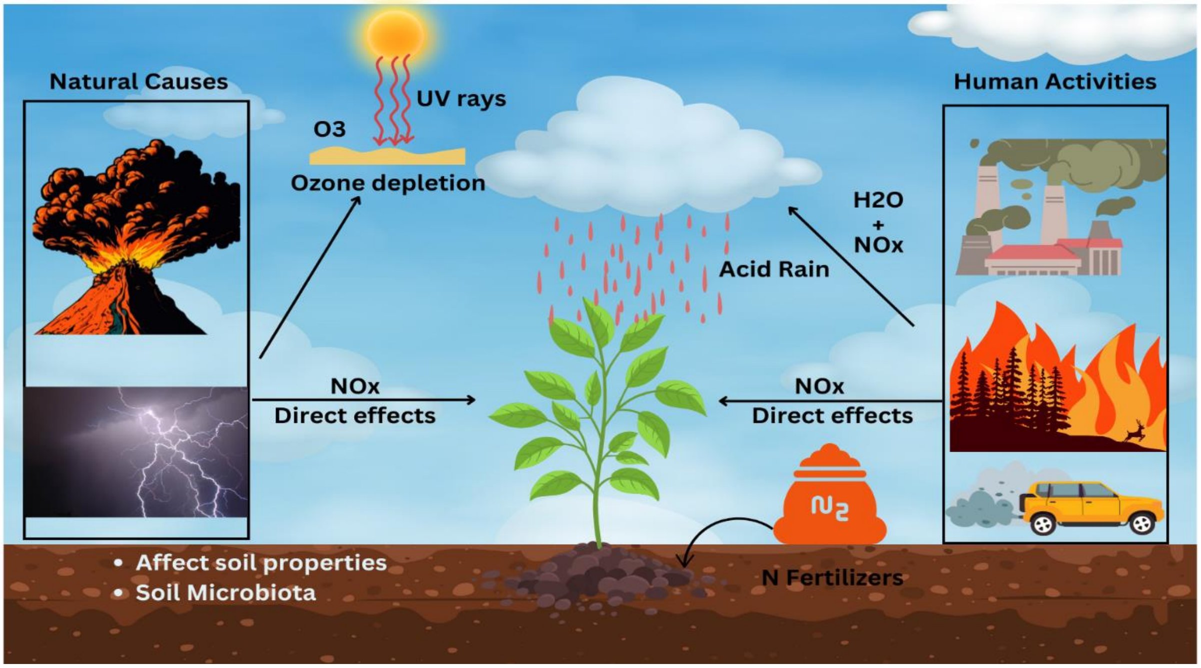

Figure 1. The major sources of NO_2 emission causing environmental pollution and degrading plant health

IMPACT OF NITROGEN ON PLANT HEALTH

The alarming rate of increase in concentrations of NO_2 in the atmosphere has generated a myriad of opinions regarding its effect on growth in plants (Marais et al., 2017). However, some scholars argue that NO_2 has no negative effects on the foliage as it is broken down and assimilated in the pathway of nitrate uptake into organic nitrogenous compounds (Sheng and Zhu, 2019). On the other hand, some suggest that NO_2 increases plant resistance, with very little NO2-N being assimilated into the total quantity of nitrogen in plants (Morikawa et al., 2001). Exposure to NO_2 also causes a plethora of physiological responses in plants, for instance, the shift of the localization of metabolic compounds within the plant tissues (Rahmat et al., 2013), increases antioxidant enzyme activity (Liu et al., 2015), and metabolic enzyme activity is modified by exposure to NO_2 (Vighi et al., 2017). Extremely minuscule quantities of NO_2 dissolve in water-based solutions forming nitrates and nitrites, which engage in nitrate metabolism (Teklemariam and Sparks, 2006). On the other hand, high NO_2 in the troposphere causes major physiological disorders and direct harm to plants, such as nitrite build-up (NO_2^-), production of reactive oxygen species, acidification of cells, suppression of nitrogen absorption, acute leaf damage, chlorosis, and plant death (Takahashi et al., 2005).

The sudden climate change is mostly caused by these harmful emissions (Tans and Keeling, 2016). Moreover, virulent races and pathotypes of plant diseases have emerged as a result of variations in NO_2 levels, disturbing planting density under favourable conditions and lowering overall output. Therefore, NO_2 is essential because it promotes physiological and biochemical reactions that strengthen plant defences against illness (Agrios, 2005). While facultative parasites experience less severe disease, high foliar nitrogen (N) availability can make plants more vulnerable to diseases, especially obligate parasites like biotrophic fungal infections (Dordas, 2008). On the other hand, obligatory parasites such as rust fungus only intensify the disease when plant growth is restricted by the availability of nitrogen (Robert et al., 2004; Walters and Bingham, 2007). It is the type of nitrogen, not the amount that determines the severity of infections produced by biotrophic fungal pathogens (Huber and Haneklaus, 2007). On the other hand, in conditions where atmospheric nitrogen is abundant, necrotrophic fungal infections typically lessen the severity of disease (Atkinson et al., 2018). In order to promote disease resistance in plants, nitrogen and phosphorus (P) are essential (Gusewell and Koerselman, 2002). Through physiological and biochemical processes, elevated NO_2 concentrations can improve photosynthetic rates and plant vigour, indirectly strengthening plant defense against diseases. As a consequence, well-fed plants demonstrate increased resistance to infections and the penetration of pathogens, thereby lowering the negative effects of environmental stressors and pathogen challenges (Olivier et al., 2023).

In conclusion, NO_2 elevated levels are associated with a variety of health-related challenges. However, the effect could possibly lead to more resistance from specific pathogens when using the appropriate metabolic pathways and physiological adaptations. However, as a whole, the negative effect of NO_2 generally outweighs this possibility, and the effects should therefore be minimized through appropriate strategic intervention to reduce the impact on plant health and productivity.

N Nutrition Impacts on the Disease Incidence

With the application of nitrogen fertilizers, there was observed an increase in diseases like leaf rust, stem rot, downy mildew and rice blast (Huang et al., 2017). Interaction of nitrogen nutrition with the susceptibility of the pathogen to infection might also produce erratic behaviour affected by various factors such as the plant growth stages, cultivar differences, and planting years (Julian Maywald et al., 2023). Nitrogen fertilization also affect disease severity, where NH_{4+} nutrition increase plant resistance to take all diseases in wheat (Sharma et al., 2020), summer patch in blue grass (Gill, 2024) and black root rot in strawberry (Bhadrecha et al., 2023). NO_3 nutrition induced resistance in the plant to Fusarium spp. (Wang et al., 2016). N-promoted plant development benefits pathogens by increasing succulent tissues, apoplastic amino acid concentrations, and improving plant canopy structure, all of which encourage the formation of pathogenic spores (Adhikari, 2024).

ROLES OF N NUTRITION IN PLANT DISEASE DEFENSES

Plants are mostly exposed to wide range of soil and air borne pathogen throughout its life which remain a continuous threat to plant normal growth and seed production. With passage of time plants have made multi layered defense system to defend against many pathogenic microorganisms like bacteria, fungus, virus and nematodes. Plants defense system is simply classified into constative and induced defense (Kant et al., 2015). Constitutive defense includes the outermost layer of plant tissue which is also known as first line of defense (Serrano et al., 2014). The interaction between the plant and microbes is very complex and influenced by many environmental factors like light temperature, humidity and nutrient (Nizamani et al., 2024). Nitrogen is particularly important as the macro-element for plant growth and development which constitute dry plant matter up-to 2% and 16% plant protein (Pruthviraj et al., 2024). N may put forward the pathogen factor with nutrients such as GABA or it may active some mechanisms in phytobacteria such as type III secretion systems. The interaction between N nutrition and plant defense is discussed in physical, chemical and molecular/biological ways and concerning the host (Fatima and Senthil-Kumar, 2015). In general, N has a negative effect on physical barriers and production of antimicrobial phytoalexins, however, has a positive effect on the defense-stress related protein and enzymes responsible for both overall and local resistance (Tripathi et al., 2022). Two other mechanisms through which N nutrition might influence defense outcomes include synthesis of hormones such as nitric oxide (NO) and modulation of transcription that depends on amino acid metabolism to affect subsequent defense-related gene regulation (Sun et al., 2020).

IMPACTS OF NITROGEN HUMAN HEALTH

Human activities such as burning of fossils fuels strongly increased the conversion of atmospheric gas N_2 into the reactive nitrogen N (Gong *et al.,* 2024). Most important forms of nitrogen are nitrogen oxides emitted mainly from industry and traffic and ammonia (NH_3) from agriculture. Nitrogen dioxide gas being considered as the third most long-lived greenhouse gas after carbon dioxide and methane has become the one of the most important cause of ozone layer depletion in stratosphere with effect of increasing the human health problems like skin cancer (Lee et al., 2013). There are evidences based on different studies that nitrogen oxides directly affect the human health. These studies were conducted on the association of variations in NOx concentration and hospitalized patients with respiratory symptoms. High concentration of NOx can increase the duration of viral infection which causes severe damage to the lungs (Kowalska et al., 2020). It is estimated that new pediatric asthma cases cause by pollution due to NO_2 are increased up to 4 million annually (Anenberg, 2019). Emission of NOx play key role in the formation of O_3 important air pollutant affecting the human health. Ozone is an important pollutant affecting human health through inhalation leads to the asthma and chronic respiratory diseases (Zhang *et al*., 2019). Children living in the area where O_3 concentration is greater have 40 % more chance to effect with asthma (Huang *et al.,* 2022). An estimated 13600 premature death are link with ozone exceeding to 35 ppb measured as maximum daily 8-h average in EU states (EEA, 2017). The estimation of pre mature death from the exposure of ground level ozone is increased from 142,000 to 358,000 World-wide between 2010 and 2050 (Evans et al., 2015).

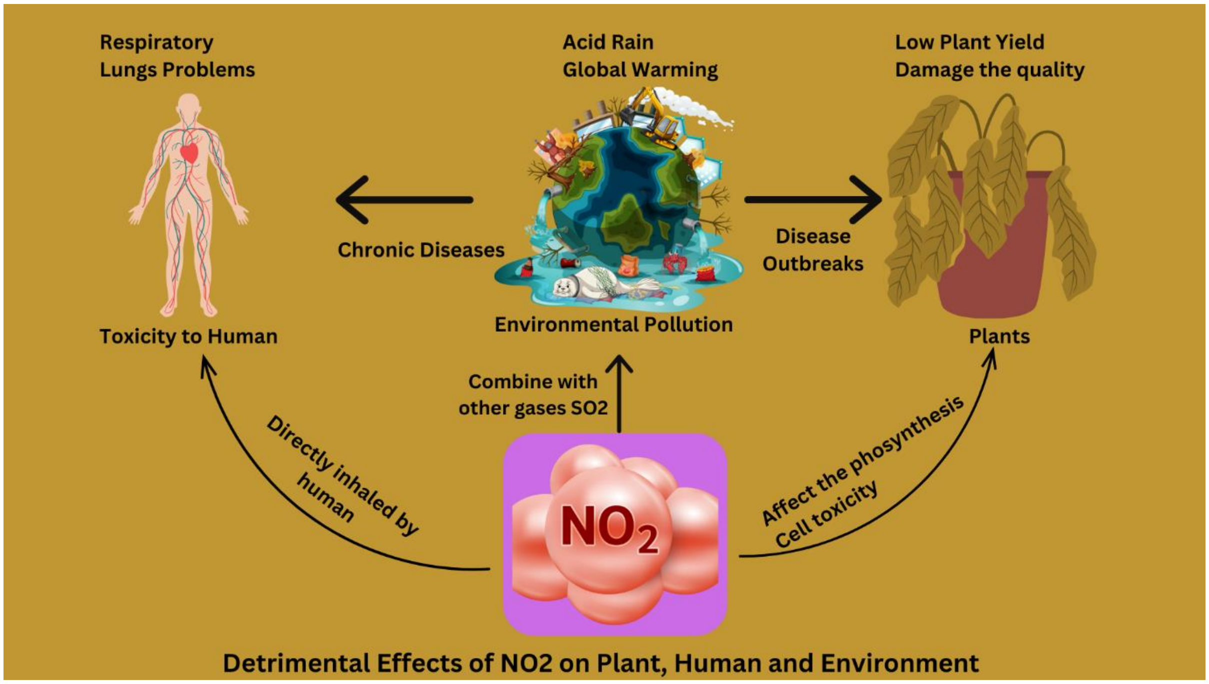

Figure 2. The detrimental effects of excessive NO_2 emission on environment as well as plant and human health

CONCLUSION

The growth and health of plants are significantly impacted by the rising nitrogen dioxide (NO_2) concentrations in the atmosphere (Sheng and Zhu, 2019). Nitrogen, which is mostly in the form of diatomic nitrogen (N_2) and makes up around 78% of the Earth's atmosphere, is inert and not directly absorbed by plants. However, because of human activity, reactive nitrogen species, such as NO_2, have significantly increased in recent decades (Follett and Hatfield, 2001). Nitrogen dioxide (NO_2), a component of nitrogen oxides (NOx), is a common greenhouse gas in the atmosphere that is mostly created by burning fossil fuels and agricultural activities (Cheng et al., 2012). Among its remarkable physicochemical characteristics are its 1.59 times density as air, 46.01 g/mol molecular weight, and -11.2°C and 21.15°C melting and boiling temperatures, respectively (Jarvis, 2010). Originally released as nitrogen monoxide (NO), NO_2 emissions from the troposphere undergo oxidation to generate NO_2, which, in the presence of sunlight, can be photolyzed back to NO, preserving photochemical equilibrium (Werner et al., 2013). In developing nations, burning biomass, burning crop waste, industry, and vehicle emissions are the main sources of NOx (Richter and Burrows, 2002). Air quality problems are exacerbated by these emissions since they lead to the production of secondary pollutants such as nitric acid (HNO_3), ozone (O_3), methane, and aldehydes (Kanaya et al., 2007). Seasonal variations, human activity, and meteorological factors all have an impact on the very fluctuating NO_2 concentrations (Colbeck et al., 2010).

Raised NO_2 concentrations can promote photosynthetic rates and plant growth by making more reactive nitrogen available (Atkinson et al., 2018). Through molecular defense mechanisms, this physiological reaction fortifies plants and increases their resistance to disease invasions (U.S. CAR, 2010). On the other hand, too much NO_2 can cause nitrite buildup, the production of reactive oxygen species, cell acidification, the suppression of nitrogen uptake, and acute leaf damage in plants (Takahashi et al., 2005). Tan and Keeling (2016) argue that NO_2 is the cause of harmful effects in terms of climate change, leading to sudden changes in climatic conditions. NO is the first one emitted from NO_2, which is then oxidized to form NO_2. This then gets reconverted to NO by the influence of sunlight, thus keeping the photochemical balance in hand (Werner et al., 2013). According to Richter and Burrows (2002) and Cheng et al. (2012), the primary NO_x emissions-emitting activities in developing countries are agricultural waste incineration, industrial activities, combustion of biomass, and automobile exhaust. Besides, Kanaya et al. (2007) and U.S. CAR (2010) also disclose that these emissions boost severe air quality problems to a large extent because they promote the formation of secondary pollutants, for example, nitric acid HNO_3, ozone O_3, methane, and aldehydes. The fluctuations in nitrogen dioxide (NO_2) concentrations are significantly influenced by meteorological conditions, seasonal changes, and anthropogenic activities (Colbeck et al., 2010).

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

The authors declare no competing interest.

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