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Review

Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring

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A R T I C L E I N F O

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A B S T R A C T

Air pollution is one of the serious problems world is facing in recent Anthropocene era of rapid industrialization and urbanization. Specifically particulate matter (PM) pollution represents a threat to both the environment and human health. The changed ambient environment due to the PM pollutant in urban areas has exerted a profound influence on the morphological, biochemical and physiological status of plants and its responses. Taking into account the characteristics of the vegetation (wide distribution, greater contact area etc.) it turns out to be an effective indicator of the overall impact of PM pollution and harmful effects of PM pollution on vegetation have been reviewed in the present paper, covering an extensive span of 1960 to March 2016. The present review critically describes the impact of PM pollution and its constituents (e.g. heavy metals and poly-aromatic hydrocarbons) on the morphological attributes such as leaf area, leaf number, stomata structure, flowering, growth and reproduction as well as biochemical parameters such as pigment content, enzymes, ascorbic acid, protein, sugar and physiological aspect such as pH and Relative water content. Further, the paper provides a brief overview on the impact of PM on biodiversity and climate change. Moreover, the review emphasizes the genotoxic impacts of PM on plants. Finally, on the basis of such studies tolerant plants as potent biomonitors with high Air Pollution Tolerance Index (APTI) and Air Pollution Index (API) can be screened and may be recommended for green belt development.

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1. Introduction

In recent Anthropocene era, rapid pace of industrialization and urbanization has given birth to dust or particulate matter (PM) pollution (Rai, 2013,2016a). Dust or PM is actually the solid matter, not only of anthropogenic origin, but also natural origin (Ferreira-Baptista and DeMiguel, 2005; Rai, 2013,2016a). Environmental contamination and human exposure with respect to dust or PM pollution have dramatically increased during the last decade, particularly in developing countries like India (Rai, 2013; Rai and Panda, 2014; Rai, 2016a). The size fractionation of PM and its adverse human health impacts have been well documented in literatures (Brook et al., 2003; Mcdonald et al., 2007; Thomas and Richard, 2010; Delfino et al., 2011; Rai, 2011a,b; Ulrich et al., 2012; Rai, 2013; Rai and Panda, 2014; Rai and Singh, 2015; Rai, 2016a,b).

The ambient air pollutants have a potential adverse impact on biochemical parameters, which further leads to a reduction in the overall growth and development of plants. The impact of various atmospheric pollutants on plants both in terms of physiology and biochemistry has been under investigation for many years (Agrawal and Agrawal, 1989; Rai, 2011a,b; Rai et al., 2013; Rai and Panda, 2014; Rai and Singh, 2015; Rai, 2016a,b). Plant adaptation to changing environmental factors involves both short-term physiological responses and long-term physiological, structural and morphological modifications. These changes help plants minimize stress and maximize use of internal and external resources (Dineva, 2004). The changed ambient environment due to the PM pollutants in urban area has exerted a profound influence on the morphological, biochemical physiological and genetic status of plants (Farooq et al., 2000a,b; Seyyednejad et al., 2011; Prajapati, 2012a,b; Younis et al., 2013; Rai et al., 2013; Rai and Panda, 2014; Rai and Singh, 2015; Rai, 2016a,b). Present review provides a critical literature review on these multifaceted aspects covering an extensive span of 1960 to March 2016. We will try to confine our review on PM; however, at some places some important references pertaining to gaseous pollutants may also appear.

Since plants are constantly exposed to air, they are the primary receptors for both gaseous and particulate pollutants of the atmosphere. In terrestrial plant species, the enormous foliar surface area acts as a natural sink for pollutants especially the particulate ones. Vegetation is an effective indicator of the overall impact of air pollution particularly in context of particulate matter (PM). The harmful effects of PM on vegetation have already been noted by several researches (Dasgupta, 1957; Keller, 1983; Agrawal et al., 1991; Rayyappa and Singara Charya, 1993; Garg et al., 2000a,b; Shrivastava and Joshi, 2002; Chandawat et al., 2011; Rai, 2011a,b; Rai, 2013; Rai and Panda, 2014; Rai and Singh, 2015; Rai, 2016a,b). Table 1 lists the important attributes of vegetation particularly road-side vegetation, which may change due to exposure of PM.

Trees have a very large surface area and their leaves function as an efficient pollutant-trapping device. Leaves, susceptible and highly exposed parts of a plant, may act as persistent absorbers for PM in a polluted environment (Maiti, 1993; Samal and Santra, 2002). The use of higher plants for air monitoring purposes is becoming more and more widespread. The main advantages are greater availability of the biological material, simplicity of species identification, sampling and treatment and ubiquity of some genera, which makes it possible to cover large areas. Lichens and mosses are characterised by irregular and patchy distribution, and their sampling should be done by specialists capable of differentiating between similar-looking species (Maiti, 1993). These limitations become more pronounced in industrial and densely populated areas, where several anthropogenic pressures may cause scarcity or even lack of indicator species at some sampling points. Therefore, the search of alternative biological indicators becomes especially important. Trees, in view of their tough physiognomy may survive in urban areas where lichens are too sensitive to survive. Therefore, trees are particularly relevant in urban areas where lichens are often missing (Rucandio et al., 2010; Rai, 2013; Rai and Singh, 2015; Rai, 2016a,b). As trees have a larger collecting surface area than other land cover types and also promote vertical transport by enhancing turbulence, there is a greater opportunity for particles to be collected on the trees surface. Trees are therefore more efficient at capturing particles from the atmosphere by dry deposition relative to short vegetation (Gallagher et al., 1997; Mcdonald et al., 2007). The sticky PM emitted from the automobile exhausts is the major constituent of PM pollution, which is deposited on the leaf surface of common roadside plants. PM reduces growth, yield, flowering, and reproduction of plants (Saunders and Godzik, 1986). PM from different sources impact on the chemical composition of plants is often used as an indicator of and a tool for monitoring environmental pollution (Rao, 1977; Posthumus, 1984, 1985; Agrawal and Agrawal, 1989; Kulump et al., 1994; Dmuchowski and Bytnerowricz, 1995; Rai, 2011a,b; Rai, 2013; Rai et al., 2013; Rai and Panda, 2014; Rai and Singh, 2015; Rai, 2016a,b).

2. Use of plants as biomonitors

Ecological investigation of impact of PM on morphological, physiological and biochemical parameters of plants assist in identifying the suitable biomonitors through calculation of air pollution tolerance index (APTI) and Anticipated Pollution Index (API). The effect of air pollution on the plants can be quantified using a parameter *i.e.* APTI. APTI is a species dependent plant attribute which expresses the inherent ability of plant to encounter stress emanating from pollution (Tiwari et al., 1993). APTI was proposed by Singh and Rao (1983) to assess the tolerant/resistance power of plants against air pollution. The APTI was calculated using the formula:

$$\text{APTI} = (A(T+P)+R)/10$$

where: A=Ascorbic Acid (mg/g)
T=Total Chlorophyll (mg/g-f w)
P=pH of the leaf extract
R=Relative water content of leaf (%).

Table 1
List of structural and functional properties of roadside vegetation which may change due to PM (Modified after Sigal and Suter, 1987; Grantz et al., 2003).

Particulate Matter Affects roadside vegetation	Structural property of roadside vegetation	Functional property of roadside vegetation
(through alteration in structural and functional properties)	***At organism/individual level***: Leaf area, Shoot morphology, Root morphology, Individual biomass, Allometry, Age distribution	Photosynthesis, Respiration, Nutrient acquisition, Nutrient leaching from foliage, Carbon allocation, Individual mortality
	At population level: Population distribution, Population dispersion, Genetic diversity, Species diversity	Competitive vigor, Reproductive success, Biomass productivity, Redundancy and resilience
	At community level: Canopy leaf area index, Root distribution, Biomass	Succession, Soil stabilization, Productivity
	At ecosystem level: Element pool sizes, Soil type	Nutrient cycling, Hydrologic cycling