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# THE EFFECTS OF ACID MIST ENVIRONMENT ON PLANT GROWTH: A REVIEW

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**Abstract**: The wet (rain, snow, fog, sleet, dew) and dry (transport of aerosol, particles and gases) deposition of acidic substance in environment results due to human, automobile, fossil fuel burning and industrial activities. Acid deposition is worldwide environmental degradation problems and in recent years these acidic materials are increasing at alarming scale in the environment both in developed and developing countries, including Pakistan. Some scientific literature survey reports suggest that plant growth and agriculture yield decrease due to consequence of acid rain. In addition, acid rain is found responsible for producing toxic effects on the morphological parameters of agricultural crop. The evidence collected from last more than fifty years showed the common significant effects of acid rain on seed germination percentage, seedling height, root hair and structure, alteration in leaf anatomy, size and area, stomatal structure, size, pollen germination, photosynthetic pigments and physiological changes in herbs, shrubs and trees. Still, little is known on the impact of acid rain on plant growth. This study was aimed to review the effects of acid mist on growth performances of some selected plant species. This review is contributed with the help of literature survey, research work published on the impact of acid rain on the plant growth.

**Key words**: fossil fuel, leaf damage, mineral nutrition, root, seed germination, shoot, water potential, yield.

## Introduction

The rapid growth of economic development, industrial and automobile activities has given rise to many common ecological and environmental pollution problems [SANKA & al. 1995; IQBAL & SHAFIQ, 2006; SHAFIQ & IQBAL, 2012; LIU & al. 2016; QIAO & al. 2018; SHAFIQ & al. 2019; IQBAL & al. 2023]. Sources of pollution depends on specific industrial activities, anthropogenic emission due to fuel combustion, geographical, geological, environmental contamination, coal combustion, climatic and sociological conditions which ones alone or in combination influence all parts of the environments. The pollutants likewise sulfur and nitrogen oxides are chemically converted in the atmosphere to form strong acids ($H_2SO_4$ and $HNO_3$) and this chemical reaction in the presence of moisture formed acid rain and increase of acidity in the environment decrease the level of alkalinity. Therefore, sulfuric and nitric acids can form and fall as acid rains [JALALI & NADERI, 2012]. The pH value of a substance determines its acidity or alkalinity and is measured on a scale of 0.0 to 14.0. The pH values less than 7.0 acidic, more than 7.0 basic, pure water has a pH of 7.0 and making it neutral [CBEF, 2013]. There are tenfold differences between each unit recorded. The pH 6 is ten times more acidic than pH 7, pH 5 is 100 times more acidic than pH 7 [GRANAT, 1972; LIKENS & al. 1972]. The pH of acid rain usually ranged about 3.0 to 5.5 [REIQUAM, 1970; DAI & al. 2013]. The effects of acid rain on soil acidification, calcium nutrition, tree growth, environmental disaster, ecological system and forest health also reported [CAP, 1993; SVERDRUP & al. 1994; DeHAYES & al. 1999; LARSSEN & al. 2006; XU & al. 2015; GUO & al. 2016; DEBNATH

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& al. 2018; BARTELS & al. 2019; LIU & al. 2019]. The maximum sulfur dioxide concentrations, exceed WHO guideline in some areas of Pakistan [UNEP, 1992]. Acid rain in 2018 affected an area of 530,000 $km^2$ in China [Ministry of Ecology and Environment of the People's Republic of China, 2018]. Acid rain availability produces harmful impact on herbs, shrub and trees. In present review the variance between pH levels 6.0 to 2.0 indicates that seed germination, seedling growth, root system, plant dry weight, pollen germination and photosynthetic activities significantly behaved differently. JU & al. (2017) stated that the precipitations with pH values lower than 5.6 as acid rain and contribute to several key environmental issues, including acidification of soils and waters, leaf injury and forest decline, loss of biodiversity, and damage of buildings and metal materials. In the natural environment, soil pH has an enormous influence on soil biogeochemical processes. Soil pH that influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield. The soil pH interlinked with the biological, geological, and chemical aspects of the soil environment as well as how these processes, through anthropogenic interventions, induce changes in soil pH [NEINA, 2019]. Acid rain describes any form of precipitation that contains high levels of nitric and sulfuric acid. It can occur in the form of snow, fog, and tiny bits of dry matter that settled on earth. Normal rain is slightly acidic with pH of 5.6 and acid rain generally range between pH 4.2 and 4.4 [NUNEZ, 2019].

The plants can be considered as the biggest victim of acid rain pollution in terrestrial ecosystem [RAMLALL & al. 2015]. It was found that simulated acid rain stress induced changes in root system, root morphology, yield and shoot: root ratio of seedlings; climate change, invertebrates, microorganism and soil respiration for nutrient uptake in forest [ERICSSON, 1995; KUPERMAN & EDWARDS, 1997; KUKI & al. 2008; REIS & al. 2012; LIANG & WANG, 2013; EL-MALLAKH & al. 2014; LIANG & al. 2015; LIANG & al. 2018; LIANG & al. 2020]. The impact of acid rain on pollen germination in corn, foliar nutrient concentrations for sugar maple, foliar injury and on the biogeochemical cycles of red spruce ecosystems noted [NEUFELD & al. 1985; LEITH & al. 1989; SHERMAN & FAHEY, 1994; HOGAN, 1998]. The disturbances in the chemical climate of earth, enzymatic and non-enzymatic antioxidant activities, ecosystem may also decrease in the pH and an increase in foliar leaching losses [COWLING, 1983; DU & al. 2020]. The possible impact of atmospheric acid deposition on leaf litters, tree leaves, root phenotypes and tree growth noted [SOLBERG & al. 2004; WANG & al. 2010; TOMAŠEVIĆ & al. 2011; SUN & al. 2013; BARTELS & al. 2019]. An important factor governing germination is the pH [HORA & BAKER, 1972]. Acid rain toxicity is deleterious to plant growth. Normally, rainfall is slightly acid, but its pH value lower than 5.6 induced high effects of on soil pH, soil microbial community, leaf injury, root, sapling and woody tree growth [ZHANG & al. 1996; OUYANG & al. 2008; PIETRI & BROOKES, 2008; MEENA, 2013; WANG & al. 2014]. Effects of simulated acid rain on the mineral nutrition, foliar pigments, biochemical attributes and photosynthetic rates of sugar maple, white spruce and wheat seedlings recorded [DIXON & KUJA, 1995; DOLATABADIAN & al. 2013]. Acidic deposition and inputs affected forest in northeastern US [DRISCOLL & al. 2001; 2003].

Acid rain pollution studies are a matter of utmost concern. Great concern has been expressed, in developed and developing countries about the toxicity role of acid rain on the immediate environment. The occurrence of incased precipitation acidity over wide areas of the city raises serious question, as it can effects on growth and vigor of plant species. This effort of research review work was carried out with the aim to highlight and understand the different types of effects of acidified rain on plant growth, soil and environmental with the help of available scientific literature covering 1970-2023. The searching was done using large database from different web sites, scientific journals, google, google scholar, scientific journals, PubMed, Hindawi, Sciencealert.net and Science Direct.

**Effects of acid mist on seed germination and seedling growth of plant**

The effects of acid rain on seed germination and seedling growth of different plant species is provided in Table 1. The interpretation of results showed a wide range of sensitivities of seed germination to acidic substrate conditions (pH 4.0, 3.0, 2.4) exists among five tree species characteristic (*Acer saccharum* L. Sapindaceae, *Acer rubrum* L. Sapindaceae, *Betula lutea* Britton Betulaceae, *Tsuga canadensis* (L.) Carrière Pinaceae and *Pinus strobus* L. Pinaceae of Adirondack mixed hardwood conifer forests [RAYNAL & al. 1982]. The rate of seed germination of Balsam fir and yellow birch showed significantly greater germination at pH 3 than at pH 4 or 5 [SCHERBATSKOY & al. 1987]. The acid rain treatment of *Vicia faba* L. cv. 'Con Amore', grown either in soil or quartz gravel in eight open top chambers to two levels of $SO_2$ (charcoal-filtered air and charcoal filtered air enriched with $SO_2$) and two artificial rain treatments (pH 5.6 and pH 3.0/4.0), alone or in combination resulted in a decrease of fresh and dry weight of whole plants, leaves, stalks, fruits and roots; number of leaves, stalks, blossoms, pods and seeds; leaf area; plant height; sulphur content total fresh and dry weight and fruit production of plants grown in soil, while, particularly at the beginning of the rain treatments, dry weight of whole potted plants and leaves as well as the number of leaves of plants grown in quartz gravel decreased [ADAROS & al. 1988].

A variable response of two years old red spruce (*Picea rubens* Sarg.) seedlings growth and foliar injury to varying pH acidity value (2.5-3.5) in concentrations of sulfur and nitrogen was observed [JACOBSON & al. 1990]. In a study, seeds and seedlings of five hardwood species were subjected to a simulated acid rain 2.0, 3.5, 5.0, 6.0 pH, and to distilled water (the control). Seed germination was remarkably inhibited by pH 2.0 treatment for three hardwood species while seedling growth was stimulated at pH levels between 3.5 and 5.0. The inhibition of seed germination and seedling growth for all the treated hardwood species was recorded by pH 2.0 treatment [FAN & WANG, 2000]. SINGH & AGRAWAL (2004) reports the effect of simulated acid rain of different pH 5.6 (control), 5.0, 4.5, 4.0 and 3.0 on two cultivars of wheat (*Triticum aestivum*, Malviya 213(M213) and Sonalika). Shoot and root lengths significantly declined at pH 3.0 in both varieties. Leaf area declined at pH 4.0 and 3.0 in M213 at both ages and at 75 days in Sonalika. Total biomass of 75 days plants declined significantly at pH range 4.5-3.0 in M213 and at pH 4.0 and 3.0 in Sonalika and concluded that acid rain has a significant negative effect on wheat plant performance.

LIU & al. (2011) reported the different effects of calcium on seed germination, seedling growth and photosynthesis of six forest tree species under simulated acid rain. The seed germination percentage, germination index of rice and wheat was absolutely inhibited with simulated acid rain stress at pH 2.0. Furthermore, rice and wheat seeds germinated abnormally at pH 2.5. An inhibition index of shoot and root length of rice, wheat and rape seeds decreased with increased pH values [ZENG & al. 2005]. Such types of studies are helpful in understanding the susceptibility of tree species to acid precipitation. Growth of five weeks old white ash (*Fraxinus americana*) was found the greatest for seedlings treated with pH 4.3 and the least for those treated with pH 5.6 or 3.0 simulated rain under controlled environmental conditions. Significant linear decreases in root dry weight, and root/shoot ratio occurred with increasing rain acidity [CHAPPELKA & CHEVONE, 2011]. Similar types of the effects of simulated acid rain (pH 2.5, 3.5,4.5 and 5.6) on the seedling growth of *Jatropha curcas* L. was recorded by [SHU & al. 2019]. The effect of varying simulated acid rain solutions treatment, one each at pH 5.6, 4.5, 3.5 and 2.5, on the growth of two crop plants, brinjal (*Solanum melongena* Linn.) and cowpea (*Vigna unguiculata* ssp. *cylindrica* (L.) Walpers was assessed [ARORA & al. 2022]. This study revealed that decrease in pH to 2.5 adversely affected almost all the growth parameters in brinjal. In case of cowpea, however, this depression was quite discernible even at pH 3.5.

**Table 1.** Effects of acid mist on seed germination and seedling growth of plant

| Name of plant species | pH range 2.0-6.0 | Symptoms | Reference |
|---|---|---|---|
| *Betula alleghaniensis* Britt. – Betulaceae | 2.3 | Seedling growth decreased | WOOD & BORMANN, 1974 |
| *Acer rubrum* L. – Sapindaceae<br>*Betula lutea* Britton – Betulaceae<br>*Pinus strobus* L. – Pinaceae | 4.0<br>3.0<br>3.0-2.4 | Inhibition<br>Inhibition<br>Stimulation | RAYNAL & al. 1982 |
| Balsam fir and yellow birch | 3 than at pH 4 or 5 | Significantly greater germination at pH 3 than at pH 4 or 5 | SCHERBATSKOY & al. 1987 |
| *Vicia faba* L. cv. 'Con Amore' | 5.6 and 3.0/4.0) | Decrease of fresh and dry weight, stalks, fruits and roots; number of leaves, stalks, blossoms, pods and seeds; leaf area; plant height; sulphur content, fruit production, and leaves as well as the number of leaves of plants | ADAROS & al. 1988 |
| *Pinus taeda* L. | 5.30, 4.0 - | Seedling height and diameter growth decrease | EDWARDS & al. 1990 |
| *Acer accharum* Marsh.<br>*Picea glauca* (Moench) Voss | 3.2 | Decreased seedling height | DIXON & KUJA, 1995 |
| *Clitorea ternatea* L.<br>*Senna holosericea* (Fresen.) Greuter.<br>*Adenanthera pavonina* L.<br>*Senra incana Cav.* | 4.0, 3.0 | Seed germination and early seedling growth decreased<br><br>Root/shoot inhibited | SHAUKAT & SHAFIQ, 1998 |
| *a=Cinnamomum camphora* L. – Lauraceae<br>*b=Castanopsis fissa* Rehd. et Wils. – Fagaceae<br>*c=Koelreuteria bipinnata* Franch. – Sapindaceae | 2.0 | a=reduction [51.09%]<br><br>b=reduction [76.61%]<br><br>c=reduction [56.32%] | MUNZUROGLU & WANG, 2000 – China |
| *Cinnamomum camphora* L.<br>*Castanopsis fissa* Rehd. et Wils.<br>*Koelreuteria bipinnata* Franch.<br>*Ligustrum lucidum* Ait.<br>*Melia azedarach* L. | 2.0 | Seedling growth adversely decreased | FAN & WANG, 2000 – China |
| Two cultivars of wheat (*Triticum aestivum,* 'Malviya' 213(M213) and 'Sonalika') | 5.6, 5.0, 4.5, 4.0 and 3.0 | Shoot and root lengths significantly declined at pH 3.0 in both varieties.<br>Leaf area declined at pH4.0 and 3.0 in M213.<br>Total biomass declined significantly at pH range4.5–3.0 in M213 and at pH 4.0 and 3.0 in Sonalika | SINGH & AGRAWAL, 2004 |
| Rice and wheat | 2 | Seedling inhibition | ZENG & al. 2005 |
| Tomato | 2.5 | inhibition of growth | DEBNATH & al. 2018 |
| *Jatropha curcas* L. – Euphorbiaceae | 4.50 (+) | Seedling growth stimulated | SHU & al. 2019 – China |
| Two crop plants, brinjal (*Solanum melongena* Linn.) and cowpea (*Vigna unguiculata* ssp. *cylindrica* (L.) Walpers | 5.6, 4.5, 3.5, 2.5 | 2.5 adversely affected almost all the growth parameters in brinjal. In case of cowpea, this depression was quite discernible even at pH 3.5. | ARORA & al. 2022 |

**Effects of different concentrations of acid mist pH (T1-2.82, T2-3.45, T3-4.46, T4-5.55) on root, shoot, seedling height and seedling dry weight of *Albizia lebbeck***

The shoot growth of *Albizia lebbeck* (L.) Benth. at pH 4.46 was found promotory. A sharp decline in shoot growth of *A. lebbeck* was noticed in pH 5.55 and 3.45 followed by pH 2.82 and 4.46 treatment, respectively (Table 2). The maximum reduction in shoot growth of *A. lebbeck* at 5.5 pH was recorded. The acid rain not only affects the aerial parts of plant but also degrade the fertility of soil and increases the vulnerability of plants to toxic metals [DU & al. 2017].

**Table 2.** Effects of different concentrations of acid mist pH on seedling growth and dry weight of *Albizia lebbeck*

| Treatments | Root length (cm) | Shoot length (cm) | Plant height (cm) | Seedling dry weight (g) |
|---|---|---|---|---|
| T1 | 16.00 | 12.20 | 28.10 | 2.856 |
| T2 | 20.00 | 11.70 | 31.70 | 2.992 |
| T3 | 15.40 | 11.70 | 27.10 | 2.878 |
| T4 | 14.10 | 10.50 | 24.60 | 2.308 |
| L.S.D. P<0.05 | 9.32 | 2.28 | 10.64 | 1.421 |
| Source: IQBAL & SHAFIQ (2023) – Pakistan | | | | |

**The effects of acid mist on leaf growth, anatomy and stomata of plant species**

The relative sensitivities of foliage of foliage of several clones of *Tradescantia* sp., *Pteridium aquilinum*, *Quercus palustris*, and *Glycine max* to acid rain, and leaf surface and anatomical alterations to simulated acid rain at pH 5.7, 3.4, 3.1, 2.9, 2.7, 2.5, and 2.3 levels was investigated [EVANS & CURRY, 1979]. Sporophyte leaves of bracken fern (*P. aquilinum*) were most sensitive to simulated acid rain among the species tested. About 10% of the surface area of older leaves of *P. aquilinum* was injured after exposure to 10 rainfalls at pH 2.5 (a single 20-min rainfall daily). The gall formation that resulted from both cell hypertrophy and hyperplasia occurred in lesions of *Tradescantia*, and *Q. Palustris* [EVANS & CURRY, 1979]. In general, it was concluded that the tested plant species that show cell hyperplasia and hypertrophy of leaf tissues after exposure to simulated acid rain.

Acid rain can negatively impact on micromorphology, leaf function and anatomy of plant health [SILVA & al. 2005; SANT'ANNA-SANTOS & al. 2006; TONG & al. 2014; WU & LIANG, 2017; MA & al. 2021] and suppresses leaf function and mesophyll cell (Table 3). The more acute injury of acid rain to plant foliage includes variation in stomatal conductance [DONG & al. 2017]. Acid rain can affect the structure of plant leaves, destroy the cuticle, and leaves, cause leaves to lose a large amount of nutrients likewise potassium, calcium, and magnesium and cell building [SINGH & AGRAWAL, 2007; HU & al. 2019]. The treatment of pH 4.5 ($H_2SO_4$) altered the micro morphological changes in youngest leaves, wilting of epidermal common cells and stomatal guard cells of *Joannesia princeps* [ANDRADE & al. 2020]. The visible leaf damage and anatomical alterations in two urban trees, *Liquidambar styraciflua* L. and *Fraxinus uhdei* (Wenz.) Lingelsh growing in Mexico City with sulfuric acid solutions at pH 2.5 and 3.8 reported [RODRÍGUEZ-SÁNCHEZ & al. 2020].

As an important edible part of leafy vegetables, the leaf blade is also one of the more sensitive plant parts to environmental stresses [XIONG & al. 2016; YANG & al. 2018; GAO & al. 2020]. The extent and magnitude of acid rain in Vietnam and other Asian countries have become more apparent since over the past decade. In this study, the effect of simulated acid rain (pH 5.0, 4.0, and 3.0) and control treatment (pH 6.0) are observed for three species *Brassica* *integrifolia*, *B. rapa*, and *B. juncea* in Hanoi. In pot experiment results showed that acid rain causes direct damage to leaves. Observations also revealed white spots on leaves; leaves getting discolored and gradually turning yellow, curling leaf marginal, and turning dark blue, with the most severe symptoms being necrotic leaves. Parameters of the shoot and root length, leaf area, biomass, and chlorophyll content all decrease as pH drops. In conclusion, *B. rapa* showed the highest resistance capability to acid rain compared with *B. integrifolia* and *B. juncea,* especially its proline content is the highest at pH 3.0 in three Brassicaceae species [PHAM & al. 2022].

**Table 3.** The effects of acid rain on leaf anatomy, damage and stomata of plant species

| **Name of Plant species** | **Acid rain pH 2.0 - 6.0, symptoms and reference** | | |
|---|---|---|---|
| | **2.0-6.0** | **Symptoms** | **Reference** |
| *Betula alleghaniensis* Britt – Betulaceae | 3.0 | Foliar tissue damage | WOOD & BORMANN, 1974 |
| *Pinus jeffreyi* Grev. & Balf. – Pinaceae<br>*Sequoiadendron giganteum* (Lindl.) Buchholz – Cupressaceae | 3.4<br>2.0 | Leaf chemical changes | WESTMAN & TEMPLE, 1989 – U.S.A. |
| *Picea rubens* Sarg. | 3.5 | Foliar injury | JACOBSON & al. 1990 – U.S.A. |
| *Picea abies* L. Karst.<br>*Pinus sylvestris* L. | 4.0<br>3.0 | Alteration in the size of the ultrastructure of needles of mesophyll chloroplasts | BÄCK & HUTTUNEN, 1992 |
| Both conifers and broadleaved tree seedlings | 3.5 | Subtle changes in the structural characteristics of leaf surfaces | CAPE, 1993 |
| Shortleaf pine – *Pinus echinata* Mill. | 5.3, 4.3, 3.3 | Leaf area affected | SHELBURNE & al. 1993 |
| Red spruce – *Picea rubens* Sarg. | 3.0 | Impaired stomatal functions, including a smaller maximum aperture, slower closure and an increased lag time between stomatal closure. Delayed stomatal closure | BORER & al. 2005 |
| *Liquidambar formosana*<br>*Schima superba* | 3.0 | Leaf necrosis | CHEN & al. 2013 |
| *Liquidambar styraciflua* L. – Altingiaceae | 2.5, 3.8 | Cuticle alterations | RODRÍGUEZ-SÁNCHEZ & al. 2020 – Mexico |
| *Fraxinus uhdei* (Wenz.) Lingelsh. – Oleaceae | 2.5, 3.8 | Visible leaf damage, anatomical alterations | RODRÍGUEZ-SÁNCHEZ & al. 2020 – Mexico |
| *Joannesia princeps* Vell – Euphorbiaceae | 4.5 | Wilting epidermal and stomata guard cell | ANDRADE & al. 2020 – Brazil |
| Pak choi (*Brassica rapa* subsp. *chinensis*) | 3.5 | Growth retardation and leaf yellowing | ZHA & al. 2022 |
| *Brassica integrifolia*<br>*Brassica rapa*<br>*Brassica juncea* in Hanoi | 3.0 | white spots on leaves; leaves getting discolored and gradually turning yellow, curling leaf marginal, turning dark blue, severe symptoms being necrotic leaves | PHAM & al. 2022 |

**The effects of acid rain on root system (root phenotypes, growth, mineral content) of plant species**

Root systems provide mechanical support and helps in nutrient uptakes and the addition of acid rain usually damage the plant root growth (Table 4). The diameter growth of white oak were significantly decreased to rains of pH 3.6 [WALKER & McLAUGHLIN, 1991]. Acid rain threatens the development of plant roots [HUANG & al. 2000; LIU & al. 2018b]. The research work of HUANG & al. (2019) shows that acid rain increases the accumulation of reactive oxygen species and inhibits roots growth and root system development of white oak (*Quercus alba* L.) and loblolly pine (*Pinus taeda* L.) were examined. The effects of topsoil heavy metal pollution (3,000 mg $kg^{-1}$ Zn, 640 mg $kg^{-1}$ Cu, 90 mg $kg^{-1}$ Pb and 10 mg $kg^{-1}$ Cd) and (synthetic) acid rain (pH 3.5) on tree growth and water use efficiency of young forest ecosystems consisting of Norway spruce (*Picea abies*), willow (*Salix viminalis*), poplar (*Populus tremula*) and birch (*Betula pendula*) trees and a variety of understorey plants was investigated. The fine root mass was significantly reduced by heavy metal pollution in *P. abies*, *P. tremula* and *B. pendula*. Above and below ground growth was strongly inhibited by acidic subsoil in *S. viminalis* and to a lesser degree also in *P. abies* [MENON & al. 2007].

**Table 4.** The effects of acid rain on root system (root phenotypes, growth, mineral content) of plant species

| Name of plant species | Acid rain pH 2.0 - 6.0, symptoms and reference | | |
|---|---|---|---|
| | **2.0-6.0** | **Symptoms** | **Reference** |
| White oak (*Quercus alba* L.) and Loblolly pine (*Pinus taeda* L.) | 3.6 | Growth and root system development reduced | WALKER & McLAUGHLI, 1991 |
| Soybean (*Glycine max* L.) | 3.0 | Root phenotype | SUN & al. 2013 |
| Rice *Oryza sativa* L. | 2.5 | Root length, surface area, volume and number of tips reduced | ZHANG & al. 2016 |
| Rice *Oryza sativa* L. | 2.0 | Severe reduction in root growth | JU & al. 2017 |
| Rice *Oryza sativa* L. | 4.5 3.5 | Reduced morphology and growth | LIU & al. 2018 |
| *Quercus acutissima* and *Cunninghamia lanceolata* | 4.5 2.5 | Damage root length and area | LIU & al. 2022 |
| *Pinus massoniana* Lamb | 4.6 | primary lateral root length, root dry weight and number of root tips in seedlings exposed to simulated acid rain at pH 4.6 were higher than that of the control (pH 6.6). | ZHOU & al. 2022 |

**The effects of acid rain on biomass of different plant species**

Some other studies that assessed similar pattern of decrease in biomass production in forests and agricultural areas (Table 5). The effects of simulated acid rain, at varying pH levels of 5.7, 4.0, 3.1 and 2.7 on yields of radish, garden beet, kidney bean, and alfalfa recorded. The results showed no significant difference in the yields of radish, kidney bean, and alfalfa when treated with simulated acid rain when compared to the yields of garden beet treated with pH 5.7 simulated rain [EVANS & al. 1982]. However, the combinations of ozone (carbon-filtered (control), ambient, 1.7 x ambient, and 2.5 x ambient) and acidic precipitation (pH 5.3, 4.3 and 3.3) for 16 months (1989 harvest) or 28 months (1990 harvest) showed trend of increased in aboveground biomass in seedlings of Shortleaf pine (*Pinus echinata* Mill.) and concluded that because N concentrations in the soils generally increased with decreasing pH [SHELBURNE &

al. 1993]. The reduction in forest productivity, water quality, the availability of nutrients due to acid stress are very common [DAHL & SKRE, 1971; SHEPPARD & al. 1993; NEAL & al. 2010]. The toxic impact of simulated acid rain on growth and yield of two cultivars of wheat noted SINGH & AGRAWAL (2004). LV & al. (2014) reported the effects of sulfuric, nitric, and mixed acid rain on litter decomposition, soil microbial biomass, and enzyme activities in subtropical forests of China. It also leads to further decreases in vertical growth, stem incremental growth, and in total plant biomass [ZHANG & al. 2016; LIU & al. 2018]. The inhibitory effects of acid rain on plant growth in general, aboveground and belowground plant parts responded differently. The interactions between acid rain pH and other acid rain characteristics and experimental characteristics indicating that there were pH dependent interaction patterns [SHI & al. 2021].

**Table 5.** The effects of acid rain on biomass of different plant species

| **Name of Plant species** | **Acid rain pH 2.0 - 6.0** | | |
|---|---|---|---|
| | **2.0 - 6.0** | **Symptoms** | **Reference** |
| *Pinus taeda* L. | 5.3, 4.0 | Biomass accumulation, seedling height and diameter growth, biomass accumulation and leaf pigment concentrations of loblolly pine | EDWARDS & al. 1990 |
| *Pinus echinata* Mill. | 5.3, 4.3, 3.3 | Biomass less | SHELBURNE & al. 1993 |
| *Vigna sinensis* L. and *Phaseolus mungo* L. | 4, 2 | Biomass accumulation, leaf chlorophyll, net photosynthesis, and photosystem activities. The level of chlorophyll on a unit fresh weight basis showed progressive reduction upon increasing acidity of mists treatment; the reduction was due to the loss of Chl a and Chl b. The increased stomatal diffusive resistance and reduced photosynthetic pigments lowered the net photosynthetic rate. | MUTHUCHELIAN & al. 1994 |
| *Zebrina pendula* | 5.6, 3.5<br>2.5,<br>1.5 | Biomass, relative anthocyanin concentration, chlorophyll content, nitrate reductase activity, proline content, antioxidase activity.<br>slightly inhibited antioxidant activity.<br>visible injury symptoms on leaves, with a sharp decline in ornamental quality. | ZHANG & al. 2014 |

**Effects of acid rain on pollen development**

Acid rain produce inhospitable environment on pollen tube elongation, germination and growth in most of the plants. The information available on the impact of acid rain on pollen germination of plants. WERTHEIM & CRAKER (1987) evaluated the properties of an acid rain episode that could influence the germination of pollen in corn (*Zea mays* L.) by treating silks with a simulated acid rain and measuring the subsequent germination of pollen on the silks. The data indicated that acid rain creates an inhospitable environment for pollen germination on the silk surface. Reduced germination appeared directly related to the acidity of the rain. Rinsing silks with a pH 5-6 rain after treatment with a pH 2-6 rain did not increase pollen germination above that on silks treated only with a pH 2-6 rain. Pollen germination on silks was inhibited even when silk tissue was exposed to a simulated rain of pH 2-6 for <1-5 min. The seed yields of corn (*Zea mays* L.) plants were significantly reduced on where the silks had been exposed to an episode of simulated acid rain at pH 3.6 as compared with yields on plants with silks exposed to simulated rain of pH 5.6. The reduction in yield appeared related to a decrease in pollen germination and tube elongation associated with acidic conditions and limited quantities of pollen available for pollination. Germination and tube elongation of pollen were also inhibited when grown on an agar medium acidified to pH 4.6 [CRAKER & WALDRON, 1989].

In the broad leaved species, pollen germination and pollen tube elongation showed sensitivities to detergent and acidity. The presence of 1 to 3 mg 1-1 sodium dodecyl-benzensulfonate detergent, or a growth medium pH of 4.0-5.0, inhibited pollen germination and pollen tube elongation more in broad leaved trees than in conifers. Pollen germination of most broad-leaved species was completely inhibited in the presence of detergent concentrations of more than 3-5 mg l-1; the only exceptions were some entomophilous species (*Salix caprea* L.) in which the ability of the pollen to germinate in high pollutant concentrations could be related to the presence of tryphyne [PAOLETTI, 1992]. The introduction of genetic material into the pollen and the production of transformed plants produced from seed formed after fertilization with treated pollen could have a tremendous impact on the improvement of economically important crops, tobacco [SMITH & al. 1994]. The effects of simulated acid fog (SAF) and temperature on stigmatic receptivity in two birch species were performed [HUGHES & COX, 1994]. Excised reproductive branches were sampled from representative individuals of mountain paper birch (*Betula cordifolia* Regel.) and paper birch (*Betula papyrifera* Marsh.) in populations adjacent to the Bay of Fundy, New Brunswick, Canada. Since 1979 these trees have exhibited branch dieback in association with abnormal foliar browning symptoms. This browning has been linked with acidity and nitrate deposited by fog, which is frequent in the area. In general, experimental results indicated that pollen germination increased with temperature, but pH effects were less obvious. Similarly, pollen tube growth responded positively to temperature and was little affected by fog acidity. ANOVA tests indicated a significant difference ($P < 0.05$) between species in their pollen germination response only at 12 °C, and not at the other three temperatures tested. For pollen tube growth, significant differences between species ($P < 0.05$) were demonstrated at 12 and 22 °C. A significant pH effect was demonstrated at 27 °C for germination, while pH effects on tube growth were significant at 27 and 12 °C ($P < 0.01$). A response surface regression analysis indicated that acidity significantly affected pollen germination in mountain paper birch ($P<0.001$) but not in paper birch. For pollen tube growth, however, temperature was more important than pH and produced highly significant effects in both species ($P<0.001$). Acidity was also a significant factor in pollen tube growth for paper birch. Effects of simulated acid precipitation (pH 5.6, 3.6, 2.6) on pollination in *Oenothera parviflora* L. from different populations were examined both *in vitro* and *in vivo*. The response of pollen *in vitro* indicated significant inhibitory effects of pH, and demonstrated that pH values ≤ 3.6 were inhibitory to both germination and tube growth, when compared with the treatment of pH 5.6. Dosages of LD50 for *in vitro* pollen germination, taken as the initial pH of cultures for the different pollens, ranged from pH 3.49 to 3.72. Stigma germination and initial tube growth on the stigmatic surface also declined significantly ($P<0.01$) in response to acid rain simulation prior to hand pollinations. Again simulants ≤ pH 3.6 significantly reduced stigma receptivity compared with the treatment at pH 5.6 [COX, 1984].

The effects of acid rain were observed on the development of anther and pollen grain in *Phaseolus vulgaris* L. (Table 6). The plants were irrigated with distilled water (pH 6.8) before treatments and considered as the control. Plants were treated by $HNO_3$ solution pH 4.5, 4, 3 and 2 separately. Plants were treated by mixed solutions of $HNO_3$ and $H_2SO_4$ pH 4.5, 4, 3, 2 separately, applying single spraying treatments. Results showed that number of pollen grains and fertile pollen were decreased in plants that treated by acid solutions. Pollen development was taking as other dicotyledonous plants. But in plants that were treated by different acidic solutions, some abnormalities were seen during pollen development. Tetrads were formed as spherical shape in normal plants but changing of tetrad shape to polygonal form is one of the treated effects by acid solutions [CHEHREGANI & al. 2006]. Pollination is a key event for fruit set. There has been an increasing interest in acid mist impact on pollen germination. Environmental conditions such as temperature, rain and high wind speed negatively affect pollination [RAMÍREZ & DAVENPORT, 2013]. A plant biostimulant is any substance or microorganism which can be applied to plants to enhance seed germination and plant growth development along with its nutritional efficiency. Plant biostimulants collectively influence: plant growth development, pollen tube development, flower and fruit set, plant pigments, shoot and root development, nutritional efficiency, yield and shelf-life of crops, rhizospheric and soil microorganisms, general soil health and plant-environment interactions. Biostimulants are derived from natural origins and can help reduce the use of chemical products and also mitigate the negative impacts of harmful chemicals in the environment. The impacts on the shelf-life and efficiencies of commercial biostimulants, as compared to synthetic chemical products and highlights the opportunities and challenges of their market expansion [GUPTA & al. 2021].

**Table 6.** Effects of acid rain on pollen germination, growth and development

| **Name of Plant species** | **Acid rain pH 2.0 - 6.0** | | |
|---|---|---|---|
| | **2.0 - 6.0** | **Symptoms** | **Reference** |
| Corn (*Zea mays* L.) | 2.6 | Inhospitable environment reduced germination of pollen | WERTHEIM & CRAKER, 1987 |
| Corn (*Zea mays* L.) | 5.6, 4.6, 3.6 | The reduction in yield appeared related to a decrease in pollen germination and tube elongation associated with acidic conditions and limited quantities of pollen available for pollination. Germination and tube elongation of pollen were also inhibited when grown on an agar medium acidified to pH 4.6 | CRAKER & WALDRON, 1989 |
| Broad leaved trees / conifers<br>Conifer | 5.0, 4.0<br>3.0-2.5 | Inhibition<br>Pollen tube elongation | PAOLETTI & al. 1992 – Italy |
| *Malus sylvestris* Miller Cv. 'Golden' | 3.3,<br>3.4 | Decreased by 41.75%<br>Pollen tube elongation 24.30% | MUNZUROGLU & al. 2003 – Turkey |
| *Phaseolus vulgaris* L. | 4.5, 4.0, 3.0, 2.0 | The number, development of anther and pollen grain decreased. Tetrads were formed as spherical shape in normal plants but changing of tetrad shape to polygonal form is one of the treated effects by acid solutions | CHEHREGANI & al. 2006 |

**The effects of acid rain on alterations and changes in photosynthetic pigments (chlorophyll a, b) in plant species**

Photosynthesis is the basic metabolic process in plant growth and development, which is very sensitive to various abiotic stresses [ZHENG & al. 2009; DONG & al. 2017; LIU & al. 2022]. Acid rain found responsible for declining photosynthetic abilities [LIU & al. 2007]. It is well known that acidic precipitations are harmful for plants, in fact, they can damage the photosynthetic machinery, plant physiology, reduce the chlorophylls content and increase the production of reactive oxygen species, while at agroecosystem levels they are responsible for the crop yield losses, above and below ground plant parts [SHU & al. 2023]. Chlorophyll fluorescence characteristics and the growth response of *Elaeocarpus glabripetalus* to simulated acid rain [LIU & al. 2015]. Industrial activity has been threatening the environment for decades and this resulted in dramatic damage of forest covers in the south-west part of Poland [JABLOŃSKI & al. 2019]. This work investigates the response to simulated acid rain on photosynthetic organs of 13 deciduous trees and 10 dicotyledonous plants (Table 7). The deleterious effects of simulated acid rain on chlorophyll contents, chlorophyll fluorescence, chlorosis, nutrient loss, enzyme activity changes in foliage of plant reported [REN & al. 2018]. Plants tolerance to stresses requires maintaining the photosynthetic apparatus [MA & al. 2019]. The application of simulated acid rains pH 3.0, 3.5, 4.0, 4.5, 5.0, 5.5 to green leaves of 13 deciduous trees and 10 species of dicotyledonous plants revealed that 77% of deciduous species represented very low to intermediate photosynthetic recovery meaning that highly acid rain impacted trees will be surviving less or none [DIATTA & al. 2021]. Acid rain of pH 3.0 inhibited plant 13C assimilation and the flow of fixed 13C to the soil. And reduces the photosynthesized C sequestration of maize soil system and soil microbial taxa interactions [LIU & al. 2023]. CHEN & al. (2013) reported photosynthetic and antioxidant responses of *Liquidambar formosana* and *Schima superba* seedlings to sulfuric rich and nitric rich simulated acid rain. *Acer amplum* subsp. *catalpifolium* is a critically endangered, native deciduous broad-leaved tree species mainly distributed in the rainy zone of west China. ZHANG & al. (2021) recorded the effects of acidity levels (pH 2.5, 3.5 and 4.5) on photosynthetic performance and stress status of *A. amplum* subsp. *catalpifolium* and conclude that simulated acid rain can enhance the peak photosynthetic rate and stomatal conductance. The significant degradation of natural ecosystem, photosynthetic performance, pigment composition, soil physiochemical and microbial properties due to pollutant stress reported [YAO & al. 2016; WEI & al. 2021]. In a study about the comparison of forest susceptibility to acid stress estimated a relative growth reduction in forest productivity in Sweden and north eastern United States [JONSSON & SUNDBERG, 1972a; JONSSON & SUNDBERG, 1972b].

The influence of different acidic mists (pH 5, 4, 2) treatment on height, biomass accumulation, leaf chlorophyll, net photosynthesis, and photosystem activities in *Vigna sinensis* L. and *Phaseolus mungo* L. were investigated [MUTHUCHELIAN & al. 1994]. The level of chlorophyll on a unit fresh weight basis showed progressive reduction upon increasing acidity of mists treatment; the reduction was due to the loss of Chl a and Chl b. The increased stomatal diffusive resistance and reduced photosynthetic pigments lowered the net photosynthetic rate. However, when various photosynthetic activities were followed in isolated chloroplast, a decrease in the rates was obtained in the seedlings exposed to pH 4 and 2. The impact of soil pH (2-6.4) on seed germination rates, plant growth, chlorophyll content, and the accumulation of phenolics on invasive weed *Phytolacca americana* (pokeweed – PaU) growing in industrially contaminated (Ulsan) and noncontaminated (Suwon-PaS) sites in South Korea were measured to assess the effects of industrial pollution and global warming related stresses on plants. The highest seed germination rate and chlorophyll content occurred at pH 2.0 for both PaU and PaS plants. Increased pH from 2-5 correlated to increased phenolic compounds and decreased chlorophyll content. However, at pH 6.4, a marked decrease in phenolic compounds, was observed and chlorophyll content increased. These results suggest that although plants from Ulsan and Suwon sites are the same species, they differ in the ability to deal with various stresses [KIM & al. 2008].

Acid rain is a frequent environmental issue in southern China that causes damage to the growth and photosystems of subtropical tree species. Arbuscular mycorrhizal fungi (AMF) can improve plant tolerance to acidic conditions [WANG & al. 2021]. In this study, the inoculated *Zelkova serrata,* an important economic tree species in China, with *Rhizophagus irregularis*, and *Diversispora versiformis*, alone and in combination, under three simulated acid rain regimes (pH 2.5, 4.0, and 5.6). The results revealed that acid rain sharply reduced photosynthetic ability and total biomass of non-mycorrhizal plants. Moreover, the acid tolerance of *Z. serrata* was positively correlated with net photosynthetic rate. Acid rain has progressively become more problematic due to increasing concentrations of atmospheric pollution, particularly in China [LY & al. 2023]. *Mirabilis jalapa* L. is an important landscaping ground cover plant with significant resistance to multiple stressors and its tolerance to acid stress was reported. In this study, the effects of acid rain on the growth and numerous physiological indexes of *M. jalapa* at different growth stages such as plant height, leaf growth, chlorophyll content, and chlorophyll fluorescence were investigated under increasingly acidic conditions of pH 5.6 (control), pH 4.0, pH 3.0, and pH 2.0. The plant height, leaf length, and leaf area of *M. jalapa* showed significantly variable results. As the simulated acid rain pH decreased, the plant height, leaf length, and leaf area showed the trend of first increasing before decreasing. In the peak at pH 4.0 treatment, the plant height, leaf length, leaf area, and chlorophyll content were significantly higher than that of the control, pH 3.0 and pH 2.0 ($P < 0.05$).

**Table 7.** The effects of acid rain on photosynthetic pigments (chlorophyll a, b) in plant species

| **Name of Plant species** | **Acid rain pH 2.0 - 6.0** | | |
|---|---|---|---|
| | **2.0 - 6.0** | **Symptoms** | **Reference** |
| *Pinus taeda* L. | 5.3, 4.0 | Leaf pigment concentrations | EDWARDS & al. 1990 |
| Red spruce (*Picea rubens* Sarg.) | 3.0 | Photosynthetic decline | BORER & al. 2005. |
| *Liquidambar formosana Schima superba* | 3.0 | Inhibited photosynthetic, soluble protein, proline content and antioxidant enzymes activities | CHEN & al. 2013 |
| Tomato seedlings | 2.5 | Inhibition of photosynthesis, severity of oxidative damage were found at pH 2.5 | DEBNATH & al. 2018 |
| Tea (*Camellia sinensis*) | 3.5, 2.5 | Restrict photosynthesis, antioxidant defense system, and metabolic disorder | ZHANG & al. 2020 - China |
| 13 deciduous tree and 10 dicotyledonous plants | 3.0, 3.5 4.0, 4.5 5.0, 5.5 | 77% of deciduous species represented very low to intermediate photosynthetic recovery | DIATTA & al. 2021 |
| *Mirabilis jalapa* L. | 4.0, 3.0, 2.0 | There are significant differences in chlorophyll fluorescence parameters under different treatments ($P < 0.05$) | LY & al. 2023 |

**The effects of acid rain on plant physiology (water relation), metabolic disorder, mineral nutrients, microbial activities in plant species**

Acid rain alters soil carbon cycling by influencing the soil microbial community structure and functions (Table 8). Previous studies have indicated that acid rain both indirectly by inducing nutrient leaching and increasing availability of toxic heavy metals [de VRIES & al. 2015]. The influence of simulated acid rain on photosynthetic pigment, proline, malondialdehyde, antioxidant enzyme activity, total nitrogen, caffeine, catechins, and free amino acids in seedlings of Tea (*Camellia sinensis*) showed that increase in acidity increased total nitrogen, certain amino acid content (theanine, cysteine), and decreased catechin and caffeine contents, resulting in an imbalance of the carbon and nitrogen metabolisms. These results further indicated that simulated acid rain at pH 3.5 and pH 2.5 could restrict photosynthesis and the antioxidant defense system, causing metabolic disorders and ultimately affecting plant development and growth [ZHANG & al. 2020]. The response of soil microbial communities to acid rain under acid rain (pH 5.0, pH 4.0, and pH 3.0) in an agricultural soil of southern China showed that the pH 3.0 acid rain increased the total, bacterial, gram positive bacterial, and actinomycetal [LIU & al. 2021].

At the same time, these effects of acid rain impact the total biomass of microorganisms and the structural distribution of different strains [WAKELIN & al. 2008; LIU & al. 2017], resulting in changes in microbial respiration. The research results showed acid rain changes soil respiration and forest type in China [FENG & al. 2002, 2017]. LIANG & al. (2016) also found that different types of forest soil have different responses to simulated acid rain, which may be caused by the differences in the acid buffering capacity of different forest stands and the original pH value of soil and litter layers [LIANG & al. 2013]. Response of soil microbial community, seed production, soil respiration and its components in a mixed coniferous broadleaved forest to simulated acid rain in the three gorges reservoir area reported [LI & al. 2011; LI & al. 2019; LI & al. 2021]. PIGNATTELLI & al. (2021) found reduction in physiology and growth of *Lepidium sativum* due to acid rain stress. All around the world, Europe, North America and Southeast Asia, especially central and southern China are affected by acidic deposition [MENZ & SEIP, 2004]. In another study, the effects of simulated acid rain pH 3.5-2.5 on the antioxidative system in *Cinnamomum philippinense* seedlings was recorded [LIU, 2011]. Plants ability depends on meteorological conditions and geochemical characteristics [AKSELSSON & al. 2013]. In Cina, the pH value of acid rain was below 5.6 is a severe environmental issue and affecting ecosystem health since 1970's [QU & HAN, 2021].

The plant water relations control the transport and loss of water evaporation from the soil. In a study, the pressure volume curves, day and night transpiration rates, needle drying curves, and shoot water potentials were determined for 2 year old red spruce trees by exposing for the three months to a range of acid mists (pH 2.5 to pH 5.0) containing equimolar $(NH_4)_2SO_4$ and $HNO_3$ [EAMUS & al. 1989]. Simulated acid rain has been reported to cause physiological changes in various plant species. SMITH & al. (1990) were conducted studies in 1983, 1984 and 1985 to determine the effect of acid rain on some physiological parameters in two corn (*Zea mays* L.) hybrids. Simulated rain of pH 3.0, 4.2, and 5.6 was applied throughout the growing season onto plots protected from ambient rain and grown on a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Argiudoll). Individual plants were evaluated for change in leaf $CO_2$ fixation, water potentials, chlorophyll content, and in vitro pollen germination.

Significant decreases in maximum turgor, the relative water content associated with zero turgor, bulk volumetric elastic modulus occurred as the pH of the mist decreased from 5.0 to 2.5 and in result the shoot water potential was declined with a decrease in pH of the mist (Table 8). The effects of simulated acid rain pH 5.1 and 3.0 and ozone (ambient and twice ambient) on tissue water relations of mature clones of a fast growing genotype of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) was investigated [MOMEN & HELMS, 1995]. The treatments showed little effect on the water relations of branches of mature trees. It was concluded that twice ambient ozone caused osmotic adjustment in seedlings, and the response was magnified by pH 3.0 rain. The low pH 4.5-6.5 reduced the propensity of *Acer rubrum* (L.) and *Quercus alba* L. to adjust leaf water relations and xylem anatomical traits in response to nutrient manipulations [MEDEIROS & al. 2016].

**Table 8.** The effects of acid rain on plant physiology (water relation), metabolic disorder, mineral nutrients, microbial activities in plant species

| Name of Plant species | Acid rain pH 2.0 - 6.0 | | |
|---|---|---|---|
| | 2.0 - 6.0 | Symptoms | Reference |
| Red spruce | 5.0, 2.5 | Shoot water potential declined | EAMUS & al. 1989 |
| Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) | 3.0 | Water relation of branches similar to drought conditions. | MOMEN & HELMS, 1995 |
| The change in the soil C/N ratio would affect the release of nutrients during the decomposition of organic matter by microorganisms | 4.0, 3.25, 2.5 | Soil organic carbon content increased, inhibiting microbial respiration. | HESSEN & al. 2004 |
| plant growth, litter, fungi | 4.0, 3.25 | Increased heavy metal content in soil, decomposition of litter by fungi increased. | ROUSK & al. 2009 |
| Juvenile Japanese red pine tree *Pinus densiflora* Sieb. et Zucc. | 3.0-2.0 | The needle gas exchange, chlorophyll fluorescence, chemical contents and visual and physiological damage to needles. | OGUNTIMEHIN & al. 2013 |
| *Acer rubrum* (L.) *Quercus alba* (L.) | 4.5 | The leaf nutrient content, water relations, leaf level and canopy level gas exchange, total biomass and allocation decreased. | MEDEIROS & al. 2016 |
| Tea (*Camellia sinensis*) | 3.5, 2.5 | Proline, malondialdehyde, antioxidant enzyme activity, total nitrogen, caffeine, catechins, and free amino acids increase catechin and caffeine contents decreased | ZHANG & al. 2020 |

## Conclusions

Many plant species have shown the harmful effects of acid mist or acid rain on plant growth. The published scientific results clearly illustrated that increase in simulated acid rain significantly decreased the germination and growth characteristics of plant. In addition, the decrease in the pH value of the simulated acid rain produced more negative impact on physiological and biochemical parameters in plants. The variable changes in the nutrient availability, photosynthetic activities and yield for plants mainly due to the low pH values available in the immediate environment. This review also highlighted the effects of acid rain on plant growth in the context of acid rain pollution as a key driving ecological indicator. Further literature research into the screening for better acid mist tolerant species is recommended. There is a need of coordination in multidisciplinary research and development programme leading to utilization of acid tolerant species for plantation at the industrial, urban centers and acid mist deposit areas. This article reviews recent developments in our knowledge of acid mist impact on plants growing in the different parts of the world.

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## References

ADAROS G., WEIGEL H. J. & JAUGER H. J. 1988. Effects of sulphur dioxide and acid rain alone or in combination on growth and yield of broad bean plants. *New Phytologist.* **108**(1): 67-74. https://doi.org/10.1111/j.1469-8137.1988.tb00205.x

AKSELSSON C., HULTBERG H., KARLSSON P. E., KARLSSON G. P. & HELLSTEN S. 2013. Acidification trends in south Swedish forest soils 1986-2008 – Slow recovery and high sensitivity to sea salt episodes. *Science of the Total Environment.* **444**: 271-287. https://doi.org/10.1016/j.scitotenv.2012.11.106

ANDRADE G. C., CASTRO L. N. & DA SILVA L. C. 2020. Micro morphological alterations induced by simulated acid rain on the leaf surface of *Joannesia princeps* Vell. (Euphorbiaceae). *Ecological Indicators*. **116**: 106526. https://doi.org/10.1016/j.ecolind.2020.106526

ARORA V., SINGH B. J. & BITHEL N. 2022. Effect of simulated acid rain on plant growth behaviour of *Solanum melongena* Linn. and *Vigna unguiculata* ssp. *cylindrica* (L.) Walp. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02726-4

BÄCK J. & HUTTUNEN S. 1992. Effects of long term exposure to simulated acid rain on conifer needle ultrastructure and hardening status. *Forest Ecology and Management.* **51**(1-3): 95-103. https://doi.org/10.1016/0378-1127(92)90475-O

BARTELS S. F., GENDREAU-BERTHIAUME B. & MACDONALD S. E. 2019. The impact of atmospheric acid deposition on tree growth and forest understory vegetation in the Athabasca Oil Sands Region. *Science of the Total Environment*. **696**: 133877. https://doi.org/10.1016 /j.scitotenv.2019.133877

BORER C. H., SCHABERG P. G. & DEHAYES D. H. 2005. Acidic mist reduces foliar membrane associated calcium and impairs stomatal responsiveness in red spruce. *Tree Physiology.* **25**(6): 673-680. https://doi.org/10.1093/treephys/25.6.673

CAPE J. N. 1993. Direct damage to vegetation caused by acid rain and polluted cloud: definition of critical levels for forest trees. *Environmental Pollution.* **82**(2): 167-180. https://doi.org/10.1016/0269-7491(93)90114-4

CBEF. 2013. CBEF (Chesapeake Bay Ecological Foundation), Inc. Acid Raid Overview. Retrieved from http://www.chesbay.org/acidRain/

CHAPPELKA A. H. & CHEVONE B. I. 2011. White ash seedling growth response to ozone and simulated acid rain. *Canadian Journal of Forest Research.* **16**(4): 786-790. https://doi.org/10.1139/x86-139

CHEHREGANI A., MALAYERI B. E., KAVIANPOUR F. & YAZDI H. L. 2006. Effect of acid rain on the development, structure and viability of pollen grains in Bean Plants (*Phaseolus vulgaris*). *Pakistan Journal of Biological Sciences.* **9**: 1033-1036. https://doi.org/10.3923/pjbs.2006.1033.1036

CHEN J., WANG W. H. , LIU T. W., WU F. H. & ZHENG H. L. 2013. Photosynthetic and antioxidant responses of *Liquidambar formosana* and *Schima superba* seedlings to sulfuric-rich and nitric rich simulated acid rain. *Plant Physiology and Biochemistry.* **64**: 41-51. https://doi.org/10.1016/j.plaphy.2012.12.012

COWLING E. B. 1983. Acid precipitation: scientific progress and public awareness. *The American Biology Teacher.* **45**(4): 194-202. https://doi.org/10.2307/4447678

COX R. M. 1984. Sensitivity of forest plant reproduction to long range transported air pollutants: *in vitro* and *in vivo* sensitivity of *Oenothera parviflora* L. pollen to simulated acid rain. *New Phytologist.* **97**(1): 63-70. https://doi .org/ 10.1111/j.1469-8137.1984.tb04109.x

CRAKER L. E. & WALDRON P. F. 1989. Acid rain and seed yield reductions in corn. *Journal of Environmental Quality.* **18**(1): 127-9. https://doi.org/10.2134/jeq1989.00472425 001800010023x

DAHL E. & SKRE O. 1971. En undersdkelse av virkningen av sur nedb6r pa produktiviteten i landbruket. *Nordforsk, Miljdvardssekretariatet.* **1**: 27-40.

DAI Z., LIU X., WU J. & XU J. 2013. Impacts of simulated acid rain on recalcitrance of two different soils. *Environmental Science and Pollution Research.* **20**(6): 4216-4224. https://doi.org/10.1007/s11356-012-1288-z

DE VRIES J., SOUSA F. L., BÖLTER B., SOLL J. & GOULD S. B. 2015. YCF1: A Green TIC? *Plant Cell*. **27**(7): 1827-1833. https://doi.org/10.1105/tpc.114.135541

DEBNATH B., IRSHAD M., MITRA S., LI M., RIZWAN H. M., LIU S., PAN T. & QIU D. 2018. Acid rain deposition modulates photosynthesis, enzymatic and non-enzymatic antioxidant activities in tomato. *International Journal of Environmental Research.* **12**: 203-214. https://doi.org/10.1007/s41742-018-0084-0

DEHAYES D. H., SCHABERG P. G., HAWLEY G. J. & STRIMBECK G. R. 1999. Acid rain impacts on calcium nutrition and forest health. *Bioscience.* **49**: 789-800. https://doi.org/10.2307/1313570

DIATTA J., YOUSSEF Y., TYLMAN O., GRZEBISZ W., MARKERT B., DROBEK L., WÜNSCHMANN S., BEBEK M., MITKO K. & LEJWODA P. 2021. Acid rain induced leakage of Ca, Mg, Zn, Fe from plant photosynthetic organs – Testing for deciduous and dicotyledons. *Ecological Indicators*. **121**: 107210. https://doi.org/10.1016/j.ecolind.2020.107210

DIXON M. J. & KUJA A. L. 1995. Effects of simulated acid rain on the growth, nutrition, foliar pigments and photosynthetic rates of sugar maple and white spruce seedlings. *Water*, *Air*, *and Soil Pollution*. **83**: 219-236. https://doi.org/10.1007/BF00477354

DOLATABADIAN A., SANAVY S., GHOLAMHOSEINI M., JOGHAN A. K., MAJDI M. & KASHKOOLI A. B. 2013. The role of calcium in improving photosynthesis and related physiological and biochemical attributes of spring wheat subjected to simulated acid rain. *Physiology and Molecular Biology of Plants*. **19**(2): 189-198. https://doi.org/10.1007/s12298-013-0165-7

DONG D., DU E., SUN Z., ZENG X. & DE VRIES W. 2017. Non-linear direct effects of acid rain on leaf photosynthetic rate of terrestrial plants. *Environmental Pollution*. **231**: 1442-1445. https://doi.org/10.1016/j.envpol. 2017.09.005

DRISCOLL C. T., DRISCOLL K. M., MITCHELL M. J. & RAYNAL D. J. 2003. Effects of acidic deposition on forest and aquatic ecosystems in New York State. *Environmental Pollution*. **123**(3): 327-336. https://doi.org/ 10.1016/s0269-7491(03)00019-8

DRISCOLL C. T., LAWRENCE G. B., BULGER A. J., BUTLER T., CRONAN C. & EAGAR C. 2001. Acidic deposition in the northeastern US: sources and inputs, ecosystems effects, and management strategies. *BioScience*. **51**(3): 180-198. https://doi.org/10.1641/0006-3568(2001)051[0180:ADITNU]2.0.CO;2

DU E., DONG D., ZENG X., SUN Z., JIANG X. & W. DE VRIES. 2017. Direct effect of acid rain on leaf chlorophyll content of terrestrial plants in China. *Science of the Total Environment*. **605-606**: 764-769. https://doi.org/10.1016/j.scitotenv.2017.06.044

DU J., QV M., ZHANG Y., CUI M. & ZHANG H. 2020. Simulated sulfuric and nitric acid rain inhibits leaf breakdown in streams: a microcosm study with artificial reconstituted fresh water. *Ecotoxicology and Environmental Safety*. **196**: 110535. https://doi.org/10.1016/j.ecoenv.2020.110535

EAMUS D., LEITH I. & FOWLER D. 1989. Water relations of red spruce seedlings treated with acid mist. *Tree Physiology*. **5**(3): 387-397. https://doi.org/10.1093/treephys/5.3.387

EDWARDS N. T., TAYLOR G. E. jr., ADAMS M. B., SIMMONS G. L. & KELLY J. M. 1990. Ozone, acidic rain and soil magnesium effects on growth and foliar pigments of *Pinus taeda* L. *Tree Physiology*. **6**(1): 95-104. https://doi.org/10.1093/treephys/6.1.95

EL-MALLAKH T. V., GAO Y. L. & EL-MALLAKH R. S. 2014. The effect of simulated acid rain on growth of root systems of *Scindapsus aureus*. *International Journal of Plant Biology*. **5**(1): 13-15. https://doi.org/10.4081/pb.2014.5187

ERICSSON T. 1995. Growth and shoot: root ratio of seedlings in relation to nutrient availability. *Plant and Soil*. **168-169**: 205-214. https://doi.org/10.1007/BF00029330

EVANS L. S. & CURRY T. M. 1979. Differential responses of plant foliage to simulated acid rain. *American Journal of Botany*. **66**(8): 953-62. https://doi.org/10.1002/j.1537-2197.1979.tb06306.x

EVANS L. S., LEWIN K. F., CUNNINGHAM E. A. & PATT M. J. 1982. Effects of simulated acidic rain on yields of field grown crops. *New Phytologist*. **91**: 429-441. https://doi.org/10.1111/j.1469-8137.1984.tb03557.x

FAN H. B. & WANG Y. H. 2000. Effects of simulated acid rain on germination, foliar damage, chlorophyll contents and seedling growth of five hardwood species growing in China. *Forest Ecology and Management*. **126**(3): 321-329. https://doi.org/10.1016/S0378-1127(99)00103-6

FENG J., WANG J., DING L., YAO P., QIAO M. & YAO S. 2017. Meta analyses of the effects of major global change drivers on soil respiration across China. *Atmospheric Environment*. **150**: 181-186.

FENG Z., MIAO H., ZHANG F. & HUANG Y. 2002. Effects of acid deposition on terrestrial ecosystems and their rehabilitation strategies in China. *Journal of Environmental Sciences – China*. **14**(2): 227-233.

FERET P. P., DIEBEL K. E. & SHARIK T. L. 1990. Effect of simulated acid rain on reproductive attributes of red spruce (*Picea rubens* Sarg.). *Environmental and Experimental Botany*. **30**(3): 309-312. https://doi.org/10.1016/0098-8472(90)90042-3

GAO P. P., XUE P. Y., DONG J. W., ZHANG X. M., SUN H. X. & GENG L. P. 2020. Contribution of PM2.5-Pb in atmospheric fallout to Pb accumulation in Chinese cabbage leaves via stomata. *Journal of Hazardous Materials*. **407**: 124356. https://doi.org/10.1016/j.jhazmat.2020.124356

GRANAT L. 1972. On the relation between pH and the chemical composition in atmospheric precipitation. *Tellus*. **24**(6): 550-560. https://doi.org/10.1111/j.2153-3490.1972.tb01581.x

GUO J., YANG Z., LIN C., LIU X., CHEN G. & YANG Y. 2016. Conversion of a natural evergreen broadleaved forest into coniferous plantations in a subtropical area: effects on composition of soil microbial communities and soil respiration. *Biology and Fertility of Soil*. **52**(6): 799-809.

GUPTA S., KULKARNI M. G., WHITE J. F., STIRK W. A., PAPENFUS H. B., DOLEŽAL K., ÖRDÖG V., NORRIE J., CRITCHLEY A. T. & STADEN J. V. 2021. Chapter 1 – Categories of various plant biostimulants – mode of application and shelf-life. In: GUPTA S., VAN STADEN J. (eds.). 2021. *Biostimulants for crops from seed germination to plant development*. Academic Press, 60 pp. https://doi.org/10.1016/B978-0-12-823048-0.00018-6

HAYES P. & ZARSKY L. 1995. *The role of science and technology in promoting environmentally sound development Seminar*. Science and Technology Policy Institute/UN University Seoul, Republic of Korea, June 13-15. https://nautilus.org/staff-publications/acid-rain-in-a- regional-context/ Accessed on 13-07-2023.

HESSEN D. O., ÅGREN G. I., ANDERSON T. R., ELSER J. J. & DE RUITER P. C. 2004. Carbon sequestration in ecosystems: the role of stoichiometry. *Ecology*. **85**(5): 1179-1192. https://doi.org/10.1890/02-0251

HOGAN G. D. 1998. Effects of simulated acid rain on physiology, growth and foliar nutrient concentrations of sugar maple. *Chemosphere*. **36**(4-5): 633-638. https://doi.org/10.1016/S0045-6535(97)10099-6

HORA T. S. & BAKER R. 1972. Extraction of a volatile factor from soil including fungistatis. *Phytopathology*. **62**: 1475-1476. https://doi.org/10.1094/Phyto-62-1475

HU X. F., WU A. Q., WANG F. C. & CHEN F. S. 2019. The effects of simulated acid rain on internal nutrient cycling and the ratios of Mg, Al, Ca, N, and pin tea plants of a subtropical plantation. *Environmental Monitoring and Assessment*. **191**(2): 99-113. https://doi.org/10.1007/s10661-019-7248-z

HUANG J., WANG H., ZHONG Y., HUANG J., FU X. & WANG L. 2019. Growth and physiological response of an endangered tree, *Horsfieldia hainanensis* Merr., to simulated sulfuric and nitric acid rain in southern China. *Plant Physiology and Biochemistry*. **144**: 118-126. https://doi.org/10.1016/j.plaphy.2019.09.029

HUANG X. H., ZHOU Q. & ZHANG X. W. 2000. The stress effect of acid rain on root growth in plant. *Argo-Environmental Protection*. **19**(4): 234-235.

HUGHES R. N. & COX R. M. 1994. Acidic fog and temperature effects on stigmatic receptivity in two birch species. *Journal of Environmental Quality*. **23**(4): 686-692. https://doi.org/10.2134/jeq1994.00472425002300040010x

IQBAL M. Z., KHAN M. H. & SHAFIQ M. 2023. Effect of polluted soil on seedling growth and development of *Phaseolus vulgaris* L. *Discovery*. **59**(327): e27d1028, 1-9.

IQBAL M. Z. & SHAFIQ M. 2006. Environment and Plants: Glimpses of research in South Asia. Nepal. 2006. "*Environmental pollution and its effects on vegetation in Pakistan*": 130-143. In: JHA P. K., CHAUDHARY R. P., KARAMCHARYA S. B. & PRASAD V. (eds.). 2006. *Environment and Plants: Glimpses of Research in South Asia*. Ecological Society (ECOS), P.O. Box 6132, Kathmandu, Nepal.

IQBAL M. Z. & SHAFIQ M. 2023.The effects of acid mist rain on the growth of *Albizia lebbeck* (L.) Bth. *New York Science Journal,* 16(7)27-33. (online).http://www. Science pub.net/newyork. 05.doi:10.7537/marsnys160 7 23.05.

JABŁOŃSKI T., TARWACKI G. & SUKOVATA L. 2019. *Pine forest conditions in Poland in 2015-2018*. In: KHARKIV P. P. (ed.). 2019. *Pine forests: current status, existing challenges and ways forward*. Proceedings of International Scientific and Practical Conference. 12-13: 83-88.

JACOBSON J. S., TWYLENE B., HELLER L. I. & LASSOIE J. P. 1990. Response of *Picea rubens* seedlings to intermittent mist varying in acidity, and in concentrations of sulfur-, and nitrogen-containing pollutions. *Physiologia Plantarum*. **78**(4): 595-601. https://doi.org/10.1111/j.1399-3054.1990.tb05247.x

JALALI M. & NADERI E. 2012. The impact of acid rain on phosphorus leaching from a sandy loam calcareous soil of western Iran. *Environmental Earth Sciences*. **66**: 311-317. https://doi.org/10.1007/s12665-011-1240-4

JONSSON B. & SUNDBERG R. 1972a. Supporting studies to air pollution across national boundaries. The impact on the environment of sulfur in air and precipitation. In: *Sweden's case study for the United Nations Conference on the Human Environment*. Stockholm: Royal Ministry of Foreign Affairs, Royal Ministry of Agriculture.

JONSSON B. & SUNDBERG R. 1972b. *Has the acidification by atmospheric pollution caused a growth reduction in Swedish forests? A comparison of growth between regions with different soil properties*. Research Note No. 20, Department of Forest Yield Research, The Royal College of Forestry, S-104 05 Stockholm 50, Sweden.

JU S. M., YIN N. N., WANG L. P., ZHANG C. Y. & WANG Y. K. 2017. Effects of silicon on *Oryza sativa* L. seedling roots under simulated acid rain stress. *PLoS One*. **12**(3): e0173378. https://doi.org/10.1371/journal.pone.0173378

KIM Y. O., RODRIGUEZ R. J., LEE E. J. & REDMAN R. S. 2008. *Phytolacca americana* from contaminated and noncontaminated soils of South Korea: Effects of elevated temperature, $CO_2$ and simulated acid rain on plant growth response. *Journal of Chemical Ecology*. **34**: 1501-1509. https://doi.org/10.1007/s10886-008-9552-x

KUKI K. N., OLIVA M. A., PEREIRA E. G., COSTA A. C. & CAMBRAIA J. 2008. Effects of simulated deposition of acid mist and iron ore particulate matter on photosynthesis and the generation of oxidative stress in *Schinus terebinthifolius* Radii and *Sophora tomentosa* L. *Science of the Total Environment*. **403**(1-3): 207-214. https://doi.org/10.1016/j.scitotenv.2008.05.004

KUPERMAN R. & EDWARDS C. A. 1997. Effects of acidic deposition on soil invertebrates and microorganisms. *Reviews of Environmental Contamination Toxicology*. **148**: 35-138.

LARSSEN T., LYDERSEN E., TANG D., HE Y. I., GAO J., LIU H., DUAN L., SEIP H. M., VOGT R. D., MULDER J., SHAO M., WANG Y., SHANG H. E., ZHANG X., SOLBERG S., AAS W., OKLAND T., EILERTSEN O., ANGELL V., LI Q., ZHAO D., XIANG R., XIAO J. & LUO J. 2006. Acid rain in China. *Environmental Science and Technology*. **40**(2): 418-425. https://doi.org/10.1021/es0626133

LEITH I. D., MURRAY M. B., SHEPPARD L. J., CAPE J. N., DEANS J. D., SMITH R. I. & FOWLER D. 1989. Visible foliar injury of red spruce seedlings subjected to simulated acid mist. *New Phytologist*. **113**: 313-320. https://doi.org/10.1111/j.1469-8137.1989.tb02409.x

LI X., WANG Y., ZHANG Y., WANG Y. & PEI C. 2021. Response of soil chemical properties and enzyme activity of four species in the Three Gorges Reservoir area to simulated acid rain. *Ecotoxicology and Environmental Safety.* **208**: 111457. https://doi.org/10.1016/j.ecoenv.2020.111457

LI Y., YANG H., XIA J., ZHANG W., WAN S. & LI L. 2011. Effects of increased nitrogen deposition and precipitation on seed and seedling production of *Potentilla tanacetifolia* in a temperate steppe ecosystem. *PLoS ONE* **6**(12): e28601. https://doi.org/10.1371/journal.pone.0028601

LI Y. F., WANG Y. J., WANG B. & WANG Y. Q. 2019. Response of soil respiration and its components to simulated acid rain in a typical forest stand in the three gorges reservoir area. *Environmental Science.* **40**: 1457-1467. https://doi.org/10.13227/j.hjkx.201803170

LIANG C. & WANG W. 2013. Antioxidant response of soybean seedlings to joint stress of lanthanum and acid rain. *Environmental Science and Pollution Research.* **20**(11): 8182-8191. https://doi.org/10.1007/s11356-013-1776-9

LIANG C. J., MA Y. J. & LI L. R. 2020. Comparison of plasma membrane H+-ATPase response to acid rain stress between rice and soybean. *Environmental Science and Pollution Research.* **27**(6): 6389-6400. https://doi.org/10.1007/s11356-019-07285-2

LIANG C. J., YQ G., SU L. & BU J. J. 2015. Response of plasma membrane H+-ATPase in rice (*Oryza sativa*) seedlings to simulated acid rain. *Environmental Science and Pollution Research International.* **22**(1): 535-545. https://doi.org/10.1007/s11356-014-3389-3

LIANG C. J. & ZHANG B. J. 2018. Effect of exogenous calcium on growth, nutrients uptake and plasma membrane H+-ATPase and Ca2+-ATPase activities in soybean (*Glycine max*) seedlings under simulated acid rain stress. *Ecotoxicology and Environmental Safety.* **165**: 261-269. https://doi.org/10.1016/j.ecoenv. 2018. 09.019

LIANG G., HUI D., WU X., WU J., LIU J., ZHOU G. & ZHANG D. 2016. Effects of simulated acid rain on soil respiration and its components in a subtropical mixed conifer and broadleaf forest in southern China. *Environmental Science*: *Process & Impacts.* **18**(2): 246-255. https://doi.org/10.1039/C5EM00434A

LIANG G., LIU X., CHEN X., QIU Q., ZHANG D., CHU G., LIU J ., LIU S. & ZHOU G. 2013. Response of soil respiration to acid rain in forests of different maturity in southern China. *PloS One.* **8**(4): e62207. https://doi.org/10.1371/journal.pone.0062207

LIKENS G. E, BORMANN F. H. & JOHNSON N. M. 1972. Acid rain. *Environment*: *Science and Policy for Sustainable Development.* **14**(2): 33-40. https://doi.org/10.1080/00139157.1972.9933001

LIU E. U. & LIU C. P. 2011. Effects of simulated acid rain on the antioxidative system in *Cinnamomum philippinense* seedlings. *Water*, *Air*, *and Soil Pollution.* **215**(1-4): 127-135. https://doi.org/10.1007/s11270-010-0464-3

LIU H., REN X., ZHU J., WU X. & LIANG C. 2018. Effect of exogenous abscisic acid on morphology, growth and nutrient uptake of rice (*Oryza sativa*) roots under simulated acid rain stress. *Planta.* **248**(3): 647-659. https://doi.org/10.1007/s00425-018-2922-x

LIU J. X., ZHOU G. Y., YANG C. W., OU Z. Y. & PENG C. L. 2007. Responses of chlorophyll fluorescence and xanthophyll cycle in leaves of *Schima superba* Gardn. & Champ. and *Pinus massoniana* Lamb. to simulated acid rain at Dinghushan biosphere reserve, China. *Acta Physiologiae Plantarum.* **29**: 33-38.

LIU L., ZHANG X. & LU X. 2016. The composition, seasonal variation, and potential sources of the atmospheric wet sulfur (S) and nitrogen (N) deposition in the southwest of China. *Environmental Science and Pollution Research.* **23**: 6363-6375. https://doi.org/10.1007/s11356-015-5844-1

LIU M. H., YI L. T., YU S. Q., YU F. & YIN X. M. 2015. Chlorophyll fluorescence characteristics and the growth response of *Elaeocarpus glabripetalus* to simulated acid rain. *Photosynthetica.* **53**(1): 23-28. https://doi.org/10.1007/s11099-015-0071-z

LIU T. W., WU F. H., WANG W. H., CHEN J., LI Z. J. & DONG X. J. 2011. Effects of calcium on seed germination, seedling growth and photosynthesis of six forest tree species under simulated acid rain. *Tree Physiology.* **31**(4): 402-413. https://doi.org/10.1093/treephys/tpr019

LIU X., MA S. L., JIA Z. H., RAMZAN M., MENG M. J. & WANG J. P. 2022. Complex effects of different types of acid rain on root growth of *Quercus acutissima* and *Cunninghamia lanceolata* saplings. *Ecological Processes.* **11**: 8-14. https://doi.org/10.1186/s13717-021-00351-z

LIU X., FU Z., ZHANG B., ZHAI L., MENG M., LIN J., ZHUANG J., WANG J. G. & ZHANG J. 2018b. Effects of sulfuric, nitric, and mixed acid rain on Chinese fir sapling growth in Southern China. *Ecotoxicology and Environmental Safety.* **160**: 154-161. https://doi.org/10.1016/j.ecoenv.2018.04.071

LIU X., ZHANG B., ZHAO W., WANG L., XIEN D., HUO W., WU Y. & ZHANG J. 2017. Comparative effects of sulfuric and nitric acid rain on litter decomposition and soil microbial community in subtropical plantation of Yangtze River Delta region. *Science of the Total Environment.* **601-602**: 669-678. https://doi.org/10.1016/j. scitotenv.2017.05.151

LIU Z., CHEN J., SU Z., LIU Z., LI Y., WANG J., WU L., WEI H. & ZHANG J. 2023. Acid rain reduces plant-photosynthesized carbon sequestration and soil microbial network complexity. *Science of The Total Environment.* **873**: 162030. https://doi.org/10.1016/j.scitotenv.2023.162030

LIU Z., WEI H., ZHANG J., SALEEM M., HE Y., ZHONG J. & MA R. 2021. Seasonality regulates the effects of acid rain on microbial community in a subtropical agricultural soil of Southern China. *Ecotoxicology and Environmental Safety*. **224**: 112681. https://doi.org/10.1016/j.ecoenv.2021.112681

LIU Z., YANG J., ZHANG J., XIANG H. & WEI H. 2019. A bibliometric analysis of research on acid rain. *Sustainability*. **11**(11): 3077. https://doi.org/10.3390/su11113077

LV Y., WANG C., JIA Y., WANG W., MA X., DU J., PU G. & TIAN X. 2014. Effects of sulfuric, nitric, and mixed acid rain on litter decomposition, soil microbial biomass, and enzyme activities in subtropical forests of China. *Applied Soil Ecology*. **79**: 1-9. https://doi.org/10.1016/j.apsoil.2013.12.002

LY C., WANG L., HY W. & ZHU X. 2023. Characterising the influence of acid rain on the growth and physiological characteristics of *Mirabilis jalapa* Linn. in southern China. *Acta Physiologiae Plantarum*. **45**: 5. https://doi.org/10.1007/s11738-022-03490-8

MA S., LIU X., JIA Z., MENG M., LI C., REN Q., ZHAI L., ZHANG B., ZHANG Y. & ZHANG J. 2021. Response of *Quercus acutissima* foliage to different types of simulated acid rain. *Atmospheric Pollution Research*. **12**(7): 101112. https://doi.org/10.1016/j.apr.2021.101112

MA Y., WANG B., ZHANG R., GAO Y., ZHANG X., LI Y. & ZUO Z. 2019. Initial simulated acid rain impacts reactive oxygen species metabolism and photosynthetic abilities in *Cinnamonum camphora* undergoing high temperature. *Industrial Crops and Products*. **135**: 352-361. https://doi.org/10.1016/j.indcrop.2019.04.050

MEDEIROS J. S., TOMEO N. J., HEWINS C. R. & ROSENTHAL D. M. 2016. Fast growing *Acer rubrum* differs from slow growing *Quercus alba* in leaf, xylem and hydraulic trait coordination responses to simulated acid rain. *Tree Physiology*. **36**(8): 1032-1044. https://doi.org/10.1093/treephys/tpw045

MEENA H. M. 2013. Acid rain-the major cause of pollution: its causes, effects and solution. *International Journal of Scientific Engineering and Technology*. **2**(9): 772-775.

MENON M., HERMLE S., GÜNTHARDT-GOERG M. S. & SCHULIN R. 2007. Effects of heavy metal soil pollution and acid rain on growth and water use efficiency of a young model forest ecosystem. *Plant and Soil*. **297**: 171-183. https://doi.org/10.1007/s11104-007-9331-4

MENZ F. C. & SEIP H. M. 2004. Acid rain in Europe and the United States: an update. *Environmental Science and Pollution Research*. **7**(4): 253-265. https://doi.org/10.1016/j.envsci.2004.05.005

Ministry of Ecology and Environment of the People's Republic of China. 2018. *Report on the State of the Ecological Environment in China* [EB/OL]. http://www.cnemc.cn/jcbg/zghjzkgb/201906/P020190618416112166768.pdf

MOMEN B. & HELMS J. A. 1995. Osmotic adjustment induced by elevated ozone: interactive effects of acid rain and ozone on water relations of field grown seedlings and mature trees of *Pinus ponderosa*. *Tree Physiology*. **15**(12): 799-805. https://doi.org/10.1093/treephys/15.12.799

MUNZUROGLU O., OBEK E. & GECKIL H. 2003. Effects of simulated acid rain on the pollen germination and pollen tube growth of Apple (*Malus sylvestris* Miller Cv. Golden). *Acta Biologica Hungarica*. **54**(1): 95-103. https://doi.org/10.1556/ABiol.54.2003.1.10

MUTHUCHELIAN K., NEDUNCHEZHIAN N. & KULANDAIVELU G. 1994. Acid rain: Acidic mist-induced response in growth and photosynthetic activities on crop plants. *Archives of Environmental Contamination and Toxicology*. **26**: 521-526. https://doi.org/10.1007/BF00214156

NEAL C., ROBINSON M., REYNOLDS B., NEAL M., ROWLAND P., GRANT S., NORRIS D., WILLIAMS B., SLEEP D. & LAWLOR A. 2010. Hydrology and water quality of the headwaters of the River Severn: stream acidity recovery and interactions with plantation forestry under an improving pollution climate. *Science of the Total Environment*. **408**(21): 5035-5051. https://doi.org/10.1016/j.scitotenv.2010.07.047

NEINA D. 2019. The role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science*. Article ID 5794869, 9 pages, 2019. https://doi.org/10.1155/2019/5794869

NEUFELD H. S., JERNSTEDT J. A. & HAINES B. L. 1985. Direct foliar effects of simulated acid rain 1. Damage, growth and gas exchange. *New Phytologist*. **99**(3): 389-405. https://doi.org/10.1111/j.1469-8137.1985.tb0 3667.x

NUNEZ C. 2019. What is acid rain? https://www.nationalgeographic.com/environment/article/acid-rain. Accessed on 13-07-2023.

OGUNTIMEHIN I., BANDAI S. & SAKUGAWA H. 2013. Mannitol can mitigate negative effects of simulated acid mist and fluoranthene in juvenile Japanese red pine (*P. densiflora* Sieb. et Zucc.). *Environmental Pollution*. **174**: 78-84. https://doi.org/10.1016/j.envpol.2012.10.023

OUYANG X., ZHOU G., HUANG Z., LIU J., ZHANG D. & LI J. 2008. Effect of simulated acid rain on potential carbon and nitrogen mineralization in forest soils. *Pedosphere*. **18**(4): 503-514.

PAOLETTI E. 1992. Effects of acidity and detergent on *in vitro* pollen germination and tube growth in forest tree species. *Tree Physiology*. **10**(4): 357-366. https://doi.org/10.1093/treephys/10.4.357

PHAM H. T. T., NGUYEN L. N., LE T. T., LE M. Q. & TRAN T. K. 2022. Impact of simulated acid rain on the growth of three species *Brassica integrifolia*, *Brassica rapa*, *Brassica juncea* in Hanoi, Vietnam. *Environmental Science and Pollution Research*. **29**: 42090-42101. https://doi.org/10.1007/s11356-022-19652-7

PIETRI J. C. A. & BROOKES P. C. 2008. Relationships between soil pH and microbial properties in a UK arable soil. *Soil Biology and Biochemistry.* **40**: 1856-1861. https://doi.org/10.1016/j.soilbio.2008.03.020

PIGNATTELLI S., BROCCOLI A., PICCARDO M., TERLIZZI A. & RENZI M. 2021. Effects of polyethylene terephthalate (PET) microplastics and acid rain on physiology and growth of *Lepidium sativum. Environmental Pollution*. **282**: 116997. https://doi.org/10.1016/j.envpol.2021.116997

QIAO F., ZHANG X. M., LIU X., CHEN J., HU W. J., LIU T. W., LIU J. Y., ZHU C. Q., GHOTO K., ZHU X. Y. & ZHENG H. L. 2018. Elevated nitrogen metabolism and nitric oxide production are involved in Arabidopsis resistance to acid rain. *Plant Physiology and Biochemistry*. **127**: 238-247. https://doi.org/10.1016/j.plaphy.2018.03.025

QU R. & HAN G. 2021. A critical review of the variation in rainwater acidity in 24 Chinese cities during 1982–2018. *Elementa Science of the Anthropocene.* **9**(1): 00142. https://doi.org/10.1525/elementa.2021.00142

RAMÍREZ F. & DAVENPORT T. L. 2013. Apple pollination: A review. *Scientia Horticulturae.* **162**: 188-203. https://doi.org/10.1016/j.scienta. 2013.08.007

RAMLALL C., VARGHESE B., RAMDHANI S., PAMMENTER N. W., BHATT A., BERJAK P. & SERSHEN. 2015. Effects of simulated acid rain on germination, seedling growth and oxidative metabolism of recalcitrant seeded *Trichilia dregeana* grown in its natural seed bank. *Physiology Plantarum.* **153**(1): 149-160. https:// doi.org/10.1111/ppl.12230

RAYNAL D. J., ROMAN J. R. & EICHENLAUB W. M. 1982. Response of tree seedlings to acid precipitation – I. Effect of substrate acidity on seed germination. *Environmental and Experimental Botany.* **22**(3): 377-383. https://doi. org/ 10.1016/0098-8472(82)90030-2

REIQUAM H. 1970. Sulfur: simulated long-range transport in the atmosphere. *Science.* **170**(3955): 318-320. https://doi.org/10.1126/science.170.3955.318

REIS S., GRENNFELT P., KLIMONT Z., AMANN M., APSIMON H., HETTELINGH J. P., HOLLAND M., LEGALL A. C., MAAS R., POSCH M., SPRANGER T., SUTTON M. A. & WILLIAMS M. 2012. Atmospheric science. From acid rain to climate change. *Science.* **338**(6111): 1153-1154. https://doi.org/10.1126/ science.1226514

REN X., ZHU J., LIU H., XU X. & LIANG C. 2018. Response of antioxidative system in rice (*Oryza sativa*) leaves to simulated acid rain stress. *Ecotoxicology and Environmental Safety.* **148**: 851-856. https://doi.org/10.1016/j.ecoenv. 2017.11.046

RODRÍGUEZ-SÁNCHEZ V. M, ROSAS U., CALVA-VÁSQUEZ G. & SANDOVAL-ZAPOTITLA E. 2020. Does acid rain alter the leaf anatomy and photosynthetic pigments in urban trees? *Plants.* **9**(7): 862. https://doi.org/10. 3390/ plants9070862

BARTELS S. F., GENDREAU-BERTHIAUME B. & MACDONALD S. E. 2019. The impact of atmospheric acid deposition on tree growth and forest understory vegetation in the Athabasca Oil Sands Region. *Science of the Total Environment.* **696**: 133877. https://doi.org/10.1016/j.scitotenv.2019.133877

SANKA M., STRNAD M. & VONDRA J. 1995. Sources of soil and plant contamination in an urban environment and possible assessment methods. *International Journal of Environmental Analytical Chemistry.* **59**(2-4): 327-343. https://doi.org/10.1080/03067319508041338

SANT'ANNA-SANTOS B. F., DA SILVA L. C., AZEVEDO A. A., DE ARAUJO J. M., ALVES E. F., DA SILVA E. A. M. & AGUIAR R. 2006. Effects of simulated acid rain on the foliar micromorphology and anatomy of tree tropical species. *Environmental and Experimental Botany.* **58**(1-3): 158-168. https://doi.org/10. 1016/j.envexpbot.2005.07.005

SCHERBATSKOY T., KLEIN R. M. & BADGER G. J. 1987. Germination responses of forest tree seed to acidity and metal ions. *Environmental and Experimental Botany.* **27**(2): 157-164. https://doi.org/10.1016/0098-8472 (87)90066-9

SHAFIQ M. & IQBAL M. Z. 2012. *Impact of automobile pollutants on plants*. LAMBERT Academic Publishing GmbH & Co. KG Heinrich-Böcking-Str. 6-8, 66121, Saarbrücken, Germany, 132 pp.

SHAFIQ M., IQBAL M. Z., KABIR M. & FAROOQI Z. 2019. *Poison Land. Vegetation of disturbed and polluted areas in Pakistan*. Strategic book publishing & rights agency, U.S.A., 173 pp.

SHAUKAT S. S. & SHAFIQ N. 1998. Effects of simulated acid rain on germination and seedling growth of some wild and cultivated species. *Pakistan Journal of Biological Sciences.* **1**(3): 219-222. https://doi.org/10.3923/pjbs.1998.219.222

SHELBURNE V. B., REARDON J. C. & PAYNTER V. A. 1993. The effects of acid rain and ozone on biomass and leaf area parameters of shortleaf pine (*Pinus echinata* Mill.). *Tree Physiology.* **12**(2): 163-72. https://doi.org/10.1093/ treephys/12.2.163

SHEPPARD L. J., CAPE J. N. & LEITH I. D. 1993. Influence of acidic mist on frost hardiness and nutrient concentrations in red spruce seedlings: 2. Effects of misting frequency and rainfall exclusion. *New Phytologist*. **124**(4): 607-615. https://doi.org/10.1111/j.1469-8137.1993.tb03850.x

SHERMAN R. E. & FAHEY T. J. 1994. The effects of acid deposition on the biogeochemical cycles of major nutrients in miniature red spruce ecosystems. *Biogeochemistry.* **24**: 85-114. https://doi.org/10.1007/BF02390181

SHI Z., ZHANG J., XIAO Z., LU T., REN X. & WEI H. 2021. Effects of acid rain on plant growth: A meta-analysis. *Journal of Environmental Management*. **297**: 113213. https://doi.org/10.1016/j.jenvman.2021.113213

SHU X., ZHANG K., ZHANG Q. & WANG W. 2023. Changes in the composition of rhizosphere bacterial communities in response to soil types and acid rain. *Journal of Environmental Management.* **325**(Part A): 116493. https://doi.org/10.1016/j.jenvman.2022.116493

SHU X., ZHANG K., ZHANG Q. & WANG W. 2019. Ecophysiological responses of *Jatropha curcas* L. seedlings to simulated acid rain under different soil types. *Ecotoxicology and Environmental Safety.* **185**: 109705. https://doi.org/10.1016/j.ecoenv.2019.109705

SILVA L., OLIVA M., AZEVEDO A., ARAÚJO J. & AGUIAR R. 2005. Micromorphological and anatomical alterations caused by simulated acid rain in Restinga plants: *Eugenia uniflora* and *Clusia hilariana. Water*, *Air*, *and Soil Pollution.* **168**: 129-143. https://doi.org/10.1007/s11270-005-0941-2

SINGH A. & AGRAWAL M. 2008. Acid rain and its ecological consequences. *Journal of Environmental Biology.* **29**(1): 15-24.

SINGH B. & AGRAWAL M. 2004. Impact of simulated acid rain on growth and yield of two cultivars of wheat. *Water*, *Air*, *and Soil Pollution.* **152**: 71-80. https://doi.org/10.1023/B:WATE.0000015331.02874.df

SINGH R. P. & AGRAWAL M. 2007. Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. *Chemosphere.* **67**(11): 2229-2240. https://doi.org/10.1016/j.chemosphere.2006.12.019

SMITH C. R., SAUNDERS J. A., WERT S. V., CHENG J. & MATTHEWS B. F. 1994. Expression of GUS and CAT activities using electrotransformed pollen. *Plant Science.* **104**(1): 49-58. https://doi.org/10.1016/0168-9452(94)90190-2

SMITH C. R., VASILAS B. L., BANWART W. L., PETERS D. B. & WALKER W. M. 1990. Lack of physiological response of two corn hybrids to simulated acid rain. *Environmental and Experimental Botany*. **30**(4): 435-442. https://doi.org/10.1016/0098-8472(90)90022-V

SOLBERG S., ANDREASSEN K., CLARKE N., TØRSETH K., TVEITO O. E. & STRAND G. H. 2004. The possible influence of nitrogen and acid deposition on forest growth in Norway. *Forest Ecology and Management.* **192**(2-3): 241-249. https://doi.org/10.1016/j.foreco.2004.01.036

SUN Z., WANG L., ZHOU Q. & HUANG X. 2013. Effects and mechanisms of the combined pollution of lanthanum and acid rain on the root phenotype of soybean seedlings. *Chemosphere.* **93**(2): 344-352. https://doi.org/10.1016/j.chemosphere.2013.04.089

SVERDRUP H., WARFVINGE P. & NIHLGÅRD B. 1994. Assessment of soil acidification effects on forest growth in Sweden. *Water*, *Air*, *and Soil Pollution.* **78**: 1-36.

TANG L., LIN Y., HE X. & HAN G. 2019. Acid rain decelerates the decomposition of *Cunninghamia lanceolata* needle and *Cinnamomum camphora* leaf litters in a karst region in China. *Ecological Research.* **34**(1): 193-200. https://doi.org/10.1111/1440-1703.1065

TOMAŠEVIĆ M., ANIČIĆ M., JOVANOVIĆ L. J., PERIĆ-GRUJIĆ A. & RISTIĆ M. 2011. Deciduous tree leaves in trace elements biomonitoring: A contribution to methodology. *Ecological Indicators.* **11**(6): 1689-1695. https://doi.org/10.1016/j.ecolind.2011.04.017

TONG S. M. & ZHANG L. Q. 2014. Differential sensitivity of growth and net photosynthetic rates in five tree species seedlings under simulated acid rain stress. *Polish Journal of Environmental Studies.* **23**(6): 2259-2264. https://doi.org/10.15244/pjoes/24930

UNEP. 1992. United Nation Environmental Programme (UNEP). *Urban Air Pollution in Mega cities of the world*. Blackwell Publisher Oxford.

WAKELIN A. S., MACDONALD L. M., ROGERS S. L., GREGG A. L., BOLGER T. P. & BALDOCK J. A. 2008. Habitat selective factors influencing the structural composition and functional capacity of microbial communities in agricultural soils. *Soil Biology and Biochemistry.* **40**(3): 803-813. https://doi.org/10.1016/j.soilbio.2007.10.015

WALKER R. F. & MCLAUGHLIN S. B. 1991. Growth and root system development of white oak and loblolly pine as affected by simulated acidic precipitation and ectomycorrhizal inoculation. *Forest Ecology and Management.* **46**(1-2): 123-133. https://doi.org/10.1016/0378-1127(91)90247-S

WANG C., GUO P., HAN G., FENG X., ZHANG P. & TIAN X. 2010. Effect of simulated acid rain on the litter decomposition of *Quercus acutissima* and *Pinus massoniana* in forest soil microcosms and the relationship with soil enzyme activities. *Science of the Total Environment.* **408**(13): 2706-2713. https://doi.org/10.1016/j.scitotenv.2010.03.023

WANG L., CHEN Z., SHANG H., WANG J. & ZHANG P. 2014. Impact of simulated acid rain on soil microbial community function in Masson pine seedlings. *Electronic Journal of Biotechnology.* **17**(5): 199-203. https://doi.org/10.1016/j.ejbt.2014.07.008

WANG Y., LIU S., SHAO C., WU A., HE X., XIA L., WANG X., QIU Y., YU S., PEI J. & ZHANG N. 2021. Enhancement of photosynthetic parameters and growth of *Zelkova serrata* by arbuscular mycorrhizal fungi under simulated sulfuric acid rain. *Plant Ecology*. **222**: 1361-1374. https://doi.org/10.1007/s11258-021-01184-8

WEI H., LIU Y., ZHANG J., LI S., ZHONG X. & XIANG H. 2021. Leaching of simulated acid rain deteriorates soil physiochemical and mechanical properties in three agricultural soils. *CATENA*. **206**: 105485. https://doi.org/10.1016/j.catena.2021.105485

WERTHEIM F. S. & CRAKER L. E. 1987. Acid rain and pollen germination in corn. *Environmental Pollution*. **48**(3): 165-172. https://doi.org/10.1016/0269-7491(87)90031-5

WESTMAN W. E. & TEMPLE P. J. 1989. Acid mist and ozone effects on the leaf chemistry of two Western Conifer species. *Environmental Pollution*. **57**(1): 9-26. https://doi.org/10.1016/0269-7491(89)90126-7

WOOD T. & BORMANN F. H. 1974. The effects of an artificial acid mist upon the growth of *Betula alleghaniensis* Britt. *Environmental Pollution*. **7**(4): 259-268. https://doi.org/10.1016/0013-9327(74)90035-4

WU X. & LIANG C. 2017. Enhancing tolerance of rice (*Oryza sativa*) to simulated acid rain by exogenous abscisic acid. *Environmental Science and Pollution Research*. **24**(5): 4860-4870. https://doi.org/10.1007/s11356-016-8219-3

XIONG T. T., AUSTRUY A., PIERART A., SHAHID M., SCHRECK E., MOMBO S. & DUMAT C. 2016. Kinetic study of phytotoxicity induced by foliar lead uptake for vegetables exposed to fine particles and implications for sustainable urban agriculture. *Journal of Environmental Sciences*. **46**: 16-27. https://doi.org/10.1016/j.jes.2015.08.029

XU H. Q., ZHANG J. E., OUYANG Y., LIN L., QUAN G. M., ZHAO B. L. & YU J. Y. 2015. Effects of simulated acid rain on microbial characteristics in a lateritic red soil. *Environmental Science and Pollution Research*. **22**: 18260-18266. https://doi.org/10.1007/s11356-015-5066-6

YANG L., XU Y. C., ZHANG R., WANG X. T. & YANG C. 2018. Comprehensive transcriptome profiling of soybean leaves in response to simulated acid rain. *Ecotoxicology and Environmental Safety*. **158**: 18-27. https://doi.org/ 10.1016/j.ecoenv.2018.04.015

YAO F. F., DING H. M., FENG L. L., CHEN J. J., YANG S. Y. & WANG X. H. 2016. Photosynthetic and growth responses of *Schima superba* seedlings to sulfuric and nitric acid depositions. *Environmental Science and Pollution Research*. **23**(9): 8644-8658. https://doi.org/10.1007/s11356-015-5970-9

ZENG Q. L., HUANG X. H. & ZHOU Q. 2005. Effect of acid rain on seed germination of rice, wheat and rape. *Huan Jing Ke Xue*. **26**(1): 181-184.

ZHA Y., TANG J. & PANG Y. 2022. The effects of simulated acid rain and cadmium-containing atmospheric fine particulate matter on the pakchoi (*Brassica campestris* L.) seedlings growth and physiology. *Soil Science and Plant Nutrition*. **68**(2): 317-328. https://doi.org/10.1080/00380768.2021.2023826

ZHANG B., BU J. & LIANG C. Root morphology and growth regulated by mineral nutrient absorption in rice roots exposed to simulated acid rain. *Water, Air, and Soil Pollution*. **227**: 457. https://doi.org/10.1007/s11270-016-3151-1

ZHANG X., GUO J., VOGT R. D., MULDER J., WANG Y., QIAN C., WANG J. & ZHANG X. 2020. Soil acidification as an additional driver to organic carbon accumulation in major Chinese croplands. *Geoderma*. **366**: 114234. https://doi.org/10.1016/j.geoderma.2020.114234

ZHANG Y., TIAN C., YU T., DAYANANDA B., FU B., SENARATNE S. L., WU C. & LI J. 2021. Differential effects of acid rain on photosynthetic performance and pigment composition of the critically endangered *Acer amplum* subsp. *catalpifolium*. *Global Ecology and Conservation*. **30**: e01773. https://doi.org/10.1016/j.gecco.2021.e01773

ZHANG Y., WU L. & WANG X. 1996. Effects of acid rain on leaf injury and physiological characteristics of crops. *AgroEnvironmental Protection*. **15**: 197-208.

ZHANG Y. B., JIAN-FEI WANG J. F., LIU A. R. & XIA H. D. 2014. Effects of simulated acid rain on the growth and antioxidant activity of *Zebrina pendula*. *Acta Prataculturae Sinica*. **23**(5): 338-344. https://doi.org/10.11686/cyxb20140540

ZHENG Y. L., FENG Y. L., LEI Y. B. & YANG C. Y. 2009. Different photosynthetic responses to night chilling among twelve populations of *Jatropha curcas*. *Photosynthetica*. **47**(4): 559-566. https://doi.org/10.1007/s11099-009-0081-9

ZHOU S., WANG P., DING Y., XIE L. & LI A. 2022. Modification of plasma membrane H+-ATPase in Masson pine (*Pinus massoniana* Lamb.) seedling roots adapting to acid deposition. *Tree Physiology*. **42**(7): 1432-1449. https://doi.org/10.1093/treephys/tpac015

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