IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Acid rain - A review

Amrita Kadchha, Charvi Pandya & Archana Mankad

Department of Botany, Bioinformatics and Climate Change Impacts Management, School of Science, Gujarat University, Ahmedabad, Gujarat, India.

Abstract: Acid rain has become a chief concern in recent times due to accretion in atmospheric pollution. Acid rain is the acidification of rainwater as a result of sulfuric acid and nitric acid which are associated with water due to the interaction with environmental components which results in their degradation. Vehicular combustion leads to the release of oxidants as air pollutants and industrial processes result in smog formation which causes increase in the acidity of rain. Even though natural acid rain isn't sufficiently acidic to burn the skin, but the effects of acid rain on plant growth can be alarming. The inhibitory effects of acid rain on germinating seeds are observed when they are treated with an acidic solution similar to that of acid rain. Young rootlets, shoots and even leaves are sensitive to acidic pH conditions, it also harms metabolic and physiological activities of the plant. Acid rain can also alter and affect the composition of soil water which acts as a main medium of nutrient source to the plants growing and soil microflora habiting in the soil. Acid rain results in foliar damage and alters the concentrations of chlorophyll in the leaf. Acid rain can cause leaching of metals that are crucial for growth and development of the plant. This review focuses on how physiological activities of seeds and plants are affected by acid rain.

Index Terms - **Simulated acid rain (SAR), environment, seeds, germination, causes and effects, plant growth**.

Introduction

The environment is enduring pollution of all its components as an undesirable change in its characteristics. The increasing emission from industries into air and burning of fossil fuel contributes to air pollution. After the late 1950s, acid rain has become one such problem as a result of extremely swift development in technology and industry. This results in rapid environmental changes which are harmful to the life existing in the biosphere. Industries discharge intolerable effluents into the environment in all three, solid, liquid, and gaseous forms. The gaseous emission reacts with atmospheric gases and results in toxic compounds and phenomena. These gaseous emissions cause air pollutions and which is a global apprehension as it leads to the disruption in the regular composition of atmospheric gases.

Acid rain- causes and effects

Industries release gases, effluent smoke, smoke from automobiles, release off CFCs- Chlorofluorocarbons from refrigerators, halons by industries into the air which causes troubles. Gases like carbon monoxide, carbon dioxide, sulfur dioxide are potentially toxic to air as they can cause alteration in other gases and components of sir. Apart from these anthropogenic causes, few natural events fuel up the pollution of air like forest fires, the release of pollen grains, greenhouse effect, dust storms, lightning, etc. (Nand Lal, 2004).

Acid rain is the precipitation of water below 4.5 pH. It can be in the wet or dry form of a deposition. It can be in the form of rain, hail, storm, fog, snow, or even dust. This results as a result of lowering of pH of rainwater, which is called acidification of rainwater. (Sonwani, 2000). Acid rain was first recorded by Smith in 1872 when he observed acidic rainwater in Manchester (Smith, 1872).Vehicular combustion leads to the release of oxidants as air pollutants and industrial processes result in smog formation which causes major discomfort and irritation to the eyes and reduces the visibility of the area. Pollutants like nitrogen oxides and lead are excluded in the air from the exhaust which gets accrued in the body. Sulfur dioxide is discarded as a result of the burning of fossil fuels in industries, vehicles, thermal plants, fertilizer producing industries, and as a result of ore smelting. (Horner, 1991). These chemicals released are considered noxious to plant health and can deteriorate plant physiological activities.

When petroleum products are burnt, combustion of coal, refineries, and metallurgical operations are carried out, as a result of the burning of fossil fuels when sulfur dioxide oxidizes into sulfur trioxide SO_3 which in combination forms sulfuric acid when reacted with water present in the atmosphere. When sulfur dioxide and sulfur trioxide counters with water they result in the formation of sulfurous acid and sulfuric acid respectively. As sulfur is omnipresent in the biosphere and fossil fuels have their elevated concentrations as it has coal and crude deposits which have approximately 1-2 % of sulfur (Smith, 2011). Apart from sulfur, aerosols which are used as disinfectants found in the air are chemicals that occur in the form of vapors or fine mist (Lal,2000). Photochemical oxidants are produced photochemically as a product of reactions between oxides of nitrogen and hydrocarbons producing secondary pollutants. These pollutants are peroxyacyl nitrates, aldehydes, and phenols. In the stratosphere: the uppermost layer of the atmosphere, the ozone layer protects living organisms in the biosphere against ultraviolet rays by absorbing the rays. The smoke and fog become smog which cause glazing and necrosis of crops.

Acid rain has also been testified in India; a rain 3.5 pH was recorded in Mumbai (Burman, 1985). In metropolitan cities like Kolkata, Mumbai, and Delhi there is a constant increase in air pollution levels. The mean pH was reduced to 6.2 from 9.8 from 1963 to 1981 at Delhi (Khemani *et. al.*, 1989).. As a result of acidification of soil due to acid rain nutrient, cycling and rate of decomposition are brutally affected (Francis *et. al*., 1982). It reduces the rate of decomposition of the litter of spruce, pine, birch, and some cellulose-rich materials (Khemani *et. al*., 1989). In Scandinavia and North America, there are records of a significant increase in the amount of aluminum and other such heavy metals like mercury, cadmium, iron, and zinc in few cases of acidified lakes which is a result of ion leaching from soil and rocks. (Dickson, 1978).
Joshi *et. al.*, 2011 analyzed the acid amount of aerosols in the surrounding air of Taj Mahal, Agra. The discard of effluents of Mathura refinery has ended up in the dullness and abrasiveness of the Taj and has caused the deterioration of stone/marble made of calcium carbonate. Due to the wash-off of calcium from the marble of Taj, the microbes like bacteria, algae, and fungi transform holes in the marble (Joshi *et. al.*, 2011). Soil is also affected by acid rain, and major three effects of acid rain on soil are:

1. Neutralization of free bases present in the soil like $CaCO_3$ or Na_2CO_3 ends up in loss of buffering capacity of soil because of episodic acidification.
2. Eradication of essential mineral nutrients from the soil which are crucial for plant growth.
3. Leaching aluminum from soil which is necessary for growth and development of flora and fauna.

Acid rain can be extremely toxic to the forest ecosystem. The acidic rainwater that seeps into the ground causes the dissolution of minerals like magnesium and calcium which are important for plant growth. Acidic rainwater is also responsible for the removal of aluminum which again causes trouble in the uptake of water. The trees that are located at a higher altitude that is on the mountains or at an elevated height like fir or spruce trees face most difficulties as they're near to acidic clouds or nearest to acidic fog. These acidic clouds and fog reduce minerals elements from the plant leaf and their needles. This reduction in the nutrients from the plant causes easy access to infections to the plants, insect attacks, and weather effects too. It also effects the phytoplankton lives in the lakes and increases their death threat as a result of the reduction in the pH.

Effects of acid rain on plants:

The effects of acid rain on the cultivar and their yield have been investigated for the last 20 years ago. As mentioned by Back and Huttenun, 1992, the effects of simulated acid rain on both the glasshouse and on-field experiments show a significant reduction in the foliage as a result of injuries (Back and Huttenun, 1992). It can also cause leaching of the all-essential nutrients from the soil and foliage (Reddt *et al*., 1996). It can cause hindrance in the reduction of seedling growth and the emergence of the seedling (Fan and Wang, 2000). Acid rain can cause a significant reduction of yield, growth, and biomass (Singh & Agrawal, 2008). Back *et al.* 1994 reported that seedling growth in resort pine is reduced by the simulated acid rain that is around pH 3.0. When the acidity is as a result of sulfuric acid unaccompanied or together with nitric acid, the decrease in growth occurs. The simulated acid rain also severely damages the cotyledon. It also reduces the leaf area, shoot height, and root length. It also causes foliar damage to crops grown in forests and fields, leaching of the micro and macronutrients and other substances from leaves and hindrance in the processes that lead to the productivity, changes in the rate of the germination depending upon how sensitive or tolerant the seed is towards the acidity. The agricultural crops that are affected the most are those which are fertilized by sulfate and nitrogen promoting growth. Potential indirect effects on forests include acidification of forest soils and accompanying alternations in soil chemistry as well as reduced forest productivity and forest dieback.

Some physiological activities like photosynthesis, stomatal conductance, etc., and few morphological attributes of plant leaves were severely affected as a result of rain (Singh & Agrawal, 2008). Acid rain can potentially shrink leaf chlorophyll content by approximately 6.71% per pH unit by causing injuries (Du *et al*., 2017). Acid rain either directly or indirectly causes consequences on plants by inhibiting photosynthesis, by chlorosis of leaves, by upsetting absorption of nutrients and minerals from the soil. (Liu H. *et. al.* 2015). It can also cause a significant increase in acidity of soil and with pH $\leq$ 4.5 there is a decrease in total free amino acids and protein content in the plant (Sulandjari & Dewi, 2018). Moreover, this acid precipitation causes soil acidification, improper nutrient supply, etc.

The acidity of the rainwater is measured using a pH scale as low pH can mutilate biological membranes, electron transport systems, and other crucial phenomena essential for the survival of the plant (Sonwani, 2020). In research, a group of monocotyledons has proven to have lesser tolerance to acidified water than dicotyledons (Lee *et al*., 1981; Singh and Agrawal, 2007; Lal, 2016). It is recorded that various physiological and morphological aspects like rate of photosynthesis, stomatal conductance etc. and leaf area, shoot and root length, number of leaves are affected by acid rain (Singh & Agrawal, 2008). The effects of Simulated acid rain (SAR) on the antioxidative enzymes, chlorophyll concentration, and lipid peroxidation were studied on cucumber plants which suggested that effects of acid rain can lead to oxidative stress in plants along with acid rain stress (Wyrwicka and Sklodowska, 2006).

The acidic deposition is a significant long-term threat to plant cultivar. It can hinder the growth of germinating seeds which may lead to the extinction of plant species and also a reduction in yield. The germinating seeds exposed to acid rain show significant symptoms of stress which are biochemical and allied with acid precipitation (Ramlal *et al*., 2015).. The seeds treated with lower pH i.e., 3.0 can display anatomical symptoms and biochemical symptoms as mentioned by Ramlal *et al*., 2015 which illuminates the effects of acid rain as the seeds show oxidative stress at root and leaf level which ultimately causes a reduction in total biomass of the seed.

Panam and Tomar, 2003 studied that simulated acid rain reduces germination %, seed vigor %, and mean germination frequency of *Oscimum sanctum*. Seedling of *Phasoleus vulgaris* acceded by SAR with pH 1.1 inhibited germination. (Ramlall *et al*., 2015).

Baldwin observed that better germination of red spruce under acidic conditions. But Raynal *et. al*. detected that seedlings inhibited emergence at lower pH levels in yellow mirch and red maple. Capron and Hutchinson observed that in groundnut there is a general decrease in length of root and shoot system with the increasing acidity. Sirohi *et.al.* observed that seed germination % and seedling growth in *Trifolium alexandrium* reduced greatly under the stress of acid rain of pH 2.0 and 3.0. Kloseiko studies the presence of elevated levels of sulfur content and nitrogen content in the leaves after they are sprayed with HNO_3 and H_2SO_4 mists. The effects of multiple pollutants are causing more stress and more deleterious effects on the plant than one single pollutant. (Chhapelka *et al*., 1985).

To reduce oxidative injury and to scavenge reactive oxygen species – ROS, the antioxidant defense system in crops was observed to be strengthened by Ren X. In response to moderate acid rain stress. Although the ROS detoxifying ability declines the extreme stress conditions as a result of changes in the metabolic status or their biosynthesis. In addition to this, acid rain causes alternation in the differentially expressed genes and transcriptional factors (Liu. *et. al*., 2011). It has been studied that different bioactive compounds such as silicon, glutathione, and melatonin can play a significant role in the improvement in abiotic stress tolerance. (Ju. *et. al*, 2020).

There is a conspicuous decrease in the content of chlorophyll a and b at higher pH- 2.5 and compared to lower pH 3.5 of acid rain in leaves of tomatoes. This decrease in chlorophyll content can lead to potential leaf senescence which is a clear indicator of acid rain stress as it leads to yellowing of leaves. The author states that chlorophyll loss is convoyed by the upregulation of chlorophyll degradation genes in leaves. For instance, SGR1 i.e., Protein STAY-GREEN 1, chloroplastic precursor and PAO- polyamine oxidase activity gene. On the other hand, the carotenoid in the leaves reduced subsequently under acid rain stress. This reduction is clearly dependent upon the pH of the acid rainwater. Acid rain stress also mutilates photosynthetic pigments. (Zhang *et. al*, 2020).

Similarly, acid rain can reduce the competence of photosystem II in seedlings of maize and amaranth. (Liu. *et. al*., 2020). In research done by Zhang, the germination of corn was severely affected by acid rain when compared to pH 6.0 with pH 1.0. The pH 1.0 had abbreviated significantly in the germination index, root length, root and shoot dry mass, germination rate, vigor index, germination velocity, shoot length, and the transformation rate of stored nutritional substances. (Zhang, 2013).

Fan and I in 1999 studied the response of seeds and seedlings of 5 broad leaves species exposed to the pH of 2.0, 3.5, and 6.0. The two lower pH were acidic while the pH 6.0 solution was distilled water. (Fay *et al*., 1983). The germination recorded marked the inhibition of emergence from seedlings at acidic pH. At pH 2.0 they studied a substantial amount of foliar damage, reduction in chlorophyll content of the seeds, and obstruction in the growth of the seedling was observed in all the broad-leaved species. Suneela and Thakre (2001). analyzed the responses of two species of rice to simulated acid rain and selected chlorophyll content and net photosynthetic rates, percent phytotoxicity, root and shoot length, and dry matter of root and shoot and their ratio as biomonitoring indices. For evaluation of relative sensitivity, some good parameters like chlorophyll content, percent phytotoxicity, and net photosynthetic rates are considered. (Suneela and Thakre, 2001). Singh and Agrawal studied that the Net Assimilation Rate in varieties of wheat and found out a significant reduction in NAR at pH 3.0. Their study concluded that there were significant negative effects on the wheat plants. (Singh & Agrawal, 2008).

Strategies to overcome acid rain:

Acid rain is a global environmental problem which requires a planned approach to overcome it. The strategies to treat acid rain are divided into two parts: 1. Strategies to control emissions that can cause acid rain from released acidic gases. In this strategy, the emissions are put under norms and policies which checks the emissions from industries and automobiles released into the atmosphere. Briefly it includes awareness about acid rain as global problem with the help of advanced technology. (Abbasi *et al.,* 2013). It includes implication of policies which will restrict the usage of sulfur, coal, and setting a limit on emission of sulfur in the atmosphere. (Hao *et al.*, 2007). 2. The strategies of receptor recovery includes recovering sites which are affected by the deposition of acid rain. For instance, soil liming, lake liming etc. These strategies include strategies which can remarkably reduce the acidity of soil which will make the soil suitable for the cultivation of crops or for the growth of flora. There are a few methods by which we can control acid rain which includes Limb Injected Multistage Burner- LIMB which is a developing technology at cheaper rate to control acid rain at some extent. Other such process is liming which is making acidic soil basic which is expensive and not affordable to everyone. Liming can make the soil excessively basic which ends up killing the organisms living in the soil too. (Fay *et al.*, 1983).

Conclusion:

As a conclusion, acid rain is one such issue which causes adverse impact on the environment globally. The gases which are responsible on a large scale are sulfur oxides and nitrogen oxides which are emitted from industries and as a result of burning of fossil fuels and automobile emissions. These gases react with components present in atmosphere and causes acid rain. Acid rain is main root of impacts on forest, crop, building, material, and acidification of soil and water in water bodies. It can also be pernicious to human health as the rain can directly come in contact with human resulting in afflictions of respiratory system, irritation or displeasure in eyes, and infections of various types in skin. To mitigate the effects of acid rain it is necessary to spread awareness among people about its causes and effects. While the government can play a significant role in the reduction by implicating policies and laws which restrains the pollutants and prevents the emissions in the atmosphere. In reduction of the deposition of acid in the soil and other ecological factors, advanced technologies can play a pivotal role by inventing cost-efficient gears which can control the emissions of baleful oxides in atmosphere or by lessening the effects of acid rain on the atmosphere.

References:

1. Abbasi, Tasneem & Poornima, P. & Kannadasan, T. & Abbasi, S. A.(2013). Acid rain: Past, present, and future. *International Journal of Environmental Engineering*. 5. 10 DOI:1504/IJEE.2013.054703.
2. Adeoye, E., Allison, P., Blackburn, C., Blocker, M., Grams, J., Jones, S., Lewis, L., Nativi, J. Ward, C. (2013). Effects of simulated acid rain on corn seed germination. Term Paper presented at the Frostburg State University, Maryland, USA. http://www.frostburg.edu/fsu/assets/File/clife/mscenter/FinalPapers/2013/Acid Rain.pdf
3. Bakhshipour Z, Asadi A, Huat BBK, Sridharan A, Kawasaki S. (2016) Effect of acid rain on geotechnical properties of residual soils. *Soils Found*. 56(6). doi:10.1016/j.sandf.2016.11.006
4. sChen, 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 Physiol. Biochem.* 64, 41–51. https://doi.org/10.1016/j.plaphy.2012.12.012
5. Debnath, B.; Irshad, M.; Mitra, S.; Li, M.; Liu, S.; Rizwan, H.M.; Pan, T.; Qiu, D. (2018) Acid rain deposition modulates photosynthesis, enzymatic and non-enzymatic antioxidant activities in tomato. *Int. J. Environ. Res.* , 12, 203–214. https://doi.org/10.1007/s41742-018-0084-0
6. Ding F, Wang R, Wang T. (2018) Enhancement of germination, seedling growth, and oxidative metabolism of barley under simulated acid rain stress by exogenous trehalose. *Crop Sci.*;58(2). doi:10.2135/cropsci2017.08.0491

7. Dolatabadian, A.; Sanavy, S.A.M.M.; 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. *Physiol. Mol. Biol. Plants* , 19, 189–198. https://doi.org/10.1007/s12298-013-0165-7
8. Du E, Dong D, Zeng X, Sun Z, Jiang X, de Vries W. (2017) Direct effect of acid rain on leaf chlorophyll content of terrestrial plants in China. *Sci Total Environ*.;605-606. doi: 10.1016/j.scitotenv.2017.06.044

9. Lee, Seok-Chan (2003) Effects of Simulated Sulfuric and Nitric Acid Rain on Growth and Seed Germination of *Arabidopsis thaliana*. *J Environ Sci*. 12(6). doi:10.5322/jes.2003.12.6.659
10. Eguagie M, Aiwansoba R, Omofomwan K, Oyanoghafo O. (2016) Impact of Simulated Acid Rain on the Growth, Yield and Plant Component of *Abelmoschus caillei*. *J Adv Biol Biotechnol*.;6(1).:1-6. doi:10.9734/jabb/2016/24804
11. Fan HB, Wang YH. (2000); Effects of simulated acid rain on germination, foliar damage, chlorophyll contents and seedling growth of five hardwood species growing in China. *For Ecol Manage*. 126(3). doi:10.1016/S0378-1127(99).00103-6
12. Gilani MM, Tigabu M, Liu B (2021);Seed germination and seedling emergence of four tree species of southern China in response to acid rain. *J For Res*. 32(2).:471-481. doi:10.1007/s11676-020-01102-0
13. Grennfelt P, Engleryd A, Forsius M, Hov Ø, Rodhe H, Cowling E. (2020); Acid rain and air pollution: 50 years of progress in environmental science and policy. *Ambio*. 49(4). doi:10.1007/s13280-019-01244-4
14. Haruna Y, Ahmad Khan A, Umar Darma Z. (2016); Effect of acid rain on growth of Papaya (*Carica papaya*). and Castor (*Ricinus communis*). plants. *J Sci Technol*. (January).:43-47.
15. Horner JM. Effects of acid rain and fluoride on plant growth. (1991) May-85-101. https://spiral.imperial.ac.uk/bitstream/10044/1/46824/2/Horner-JM-1991-PhD-Thesis.pdf
16. Huang XH, Zhou Q, Ye YX, Zhang Y. (2000); Effect of cerium on seed germination under acid rain stress. *J Rare Earths*18(4). https://doi.org/10.15258/sst.2010.38.1.03
17. Ju, S.; Wang, L.; Chen, J. (2020), Effects of silicon on the growth, photosynthesis and chloroplast ultrastructure of *Oryza sativa* L. seedlings under acid rain stress. *Silicon* 12, 655–664. https://doi.org/10.1007/s12633-019-00176-8
18. Kováčik, J.; Klejdus, B.; Bačkor, M.; Stork, F.; Hedbavny, J.(2011) Physiological responses of root-less epiphytic plants to acid rain. *Ecotoxicology* 2011, 20, 348–357 https://doi.org/10.1007/s10646-010-0585-x
19. Kumar S. (2017) Acid Rain-The Major Cause of Pollution: Its Causes, Effects. *Int J Appl Chem*.;13(1).:53-58. http://www.ripublication.com
20. Liu M, Huang X, Song (2019) Ammonia emission control in China would mitigate haze pollution and nitrogen deposition, but worsen acid rain. *Proc Natl Acad Sci U S A*.;116(16). doi:10.1073/pnas.1814880116
21. Liu, J.; Zhou, G.; Yang, C.; Ou, Z.; Peng, C. (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 Physiol. Plant. 29*, 33–38 https://doi.org/10.1007/s11738-006-0005-2
22. Liu, T.W.; Niu, L.; Fu, B.; Chen, J.; Wu, F.H.; Chen, J.; Wang, W.H.; Hu, W.J.; He, J.X.; Zheng, H.L. (2013) A transcriptomic study reveals differentially expressed genes and pathways respond to simulated acid rain in *Arabidopsis thaliana* Genome , 56, 49–60. https://doi.org/10.1139/gen-2012-0090
23. Liu, T.-W.; Wu, F.-H.; Wang, W.-H.; Chen, J.; Li, Z.-J.; Dong, X.-J.; Patton, J.; Pei, Z.-M.; Zheng, H.-L. (2011), Effects of calcium on seed germination, seedling growth and photosynthesis of six forest tree species under simulated acid rain. *Tree Physiol. 31*, 402–413. https://doi.org/10.1093/treephys/tpr019
24. Livingston RA. (2016) Acid rain attack on outdoor sculpture in perspective. *Atmos Environ*.; page-146. doi:10.1016/j.atmosenv.2016.08.029

25. Neuvonen S, Nyyssönen T, Ranta H, Kiilunen S. (1991). Simulated acid rain and the reproduction of mountain birch [*Betula pubescens ssp. tortuosa (Ledeb.). Nyman]*: a cautionary tale. *New Phytol*. 118(1). doi:10.1111/j.1469-8137.1991.tb00571.x
26. Odiyi BO, Eniola AO. (2015); The effect of simulated acid rain on plant growth component of cowpea (*Vigna unguiculata*). L. Walps. *Jordan J Biol Sci*. 8(1).:51-54. doi:10.12816/0026948
27. Patten DK. (1983). The effect of acid rain on the growth and nutrient content of two species of hardwood tree seedlings , and on the pH , microflora and nutrient content of the soil. Digital Repository @ Iowa State University, http://lib.dr.iastate.edu/ https://doi.org/10.31274/rtd-180813-8539
28. Personal M, Archive R, Mohajan H, Mohajan HK. M P RA (2018)- Acid Rain is a Local Environment Pollution but Global Concern Acid Rain is a Local Environment Pollution but Global Concern. *Open Sci J Anal Chem*. 2018;3(5).
29. Ramlall C, Varghese B, Ramdhani S, *et al*. (2015); Effects of simulated acid rain on germination, seedling growth and oxidative metabolism of recalcitrant-seeded *Trichilia dregeana* grown in its natural seed bank. *Physiol Plant*. 153(1).:149-160. doi:10.1111/ppl.12230
30. 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. *Ecotoxicol. Environ. Saf.* 2018, *148*, 851–856. https://doi.org/10.1016/j.ecoenv.2017.11.046
31. Seinfeld, J.H.; Pandis, S.N. (2012). *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*; *John Wiley & Sons:* Hoboken, NJ, USA, 2012. https://doi.org/10.1063/1.882420
32. Singh A, Agrawal M. (2008) Acid rain and its ecological consequences. *J Environ Biol*. 2008;29-42.
33. Sonwani S. (2020); Acid rain and its environmental impacts: a review. *India 2020 Environ Challenges, Policies Green Technol*. 2020;(August). https://doi.org/10.1021/es983663d
34. Sulandjari, Dewi WS. (2018) Effects of intermittent acid rain on proline and antioxidant content on medicinal plant "pereskia bleo."- *IOP Conf Ser Earth Environ Sci*. 2018;129(1). doi:10.1088/1755-1315/129/1/012020
35. Sun QS, Huang J, Wu XJ, Jiang HD, Zhou Q. (2016) Effect of different acidities of acid rain on nitrogen and sulfur metabolism and grain protein levels in wheat after anthesis. *Shengtai Xuebao/ Acta Ecol Sin*. 2016;36(1). doi:10.5846/stxb201408261692
36. Wang L, Huang X, Zhou Q. (2008) Response of peroxidase and catalase to acid rain stress during seed germination of rice, wheat, and rape. *Front Environ Sci Eng China*. 2008;2(3).:364-369. doi:10.1007/s11783-008-0053-5
37. Wen, K.; Liang, C.; Wang, L.; Hu, G.; Zhou, Q. (2011) Combined effects of lanthanum ion and acid rain on growth, photosynthesis and chloroplast ultrastructure in soybean seedlings. *Chemosphere* 2011, 84,601–608 https://doi.org/10.1016/j.chemosphere.2011.03.054
38. Zabawi AGM, Esa SM, Leong CP. (2008) Effects of simulated acid rain on germination and growth of rice plant. *J Trop Agric Food Sci*. 2008;36(2).:1-6. https://doi.org/10.15258/sst.2010.38.1.03
39. Zeng QL, Huang XH, Zhou Q.(2005) Effect of acid rain on seed germination of rice, wheat and rape. *Huanjing Kexue/Environmental Sci*. 2005;26(1).:181-184. https://doi.org/10.1007/s11783-008-0053-5
40. Zhang HY. (2013); Effects of simulated acid rain on seed germination and seedling growth of different type corn (*Zea mays*). *Chinese J Appl Ecol*. 2013;24(6). PMID: 24066549.
41. Zeng QL, Huang XH, Zhou Q. (2005) Effect of acid rain on seed germination of rice, wheat and rape Huan Jing ke Xue Huanjing Kexue. 2005 Jan;26(1).:181-184. PMID: 15859434.
42. Yuan Zhi-Zhong, Zeng Shuo, Zhou Yao-Yu Effects of Simulated Acid Rain to Seed Germination and Seedling Growth in Maize (College Of Biology Resources & Environmental Sciences, Jishou University, Jishou 416000, China).
43. Ying Yong Sheng tai xue bao, (2013) Effects of simulated acid rain on seed germination and seedling growth of different type corn- *Zea mays The Journal of Applied Ecology*. Jun;24(6).:1621-1626. PMID: 24066549.