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Effects of simulated acid rain on the growth, yield and mineral nutrient relations of *Solanum lycopersicum* L

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Abstract
This investigation was undertaken to observe the effects of simulated acid rain (SAR) on the growth, mineral nutrient accumulation and yield of *Solanum lycopersicum.* The plants were exposed to different levels of simulated acid rain acidified at pH 5.6 (control), 5.0, 4.0, 3.0 and 2.0. The experimental results indicated that under the stress of simulated acid rain, growth parameters measured such as leaf number, shoot height, fresh and dry weight and stem girth were significantly reduced in plant subjected to SAR when compared with the control treatment. There was a gradual decline in chlorophyll content index as the level of acidity increased. Chlorophyll content index was highest (11.57) at pH 5.6 and least (5.65) at pH 2.0. SAR induced morphological changes such as chlorosis and necrosis in *Solanum lycopersicum.* Phytochemical analysis of the plant showed that mineral nutrient such as Mg, Ca, Fe, K, P and N were leached at low pH. It was concluded that growth, yield and mineral nutrient retention were adversely affected when *S. lycopersicum* was exposed to simulated acid rain.

Keywords: acid rain, yield, *Solanum lycopersicum* L, mineral nutrient

Introduction

Air quality is of fundamental importance for all living organisms. Plant, animal and human health depends very much on clean atmosphere. Polluting elements such as sulphur dioxide (SO_2), oxides of Nitrogen (NO_2), carbon dioxide (CO_2) and Hydrogen fluoride (HF) which are released into the air as a result of human activities results in acid rain, following complex physiochemical reactions, sometimes aided by the presence of light (Viscas *et al*., 2009) [18]. The impact of industrial civilization on the environment may be unparalleled in history of the biosphere.

Indiscriminate and over growing use of energy may not only cause wide spread degradation of natural resources but may also influence our life support system (Arti *et al*., 2010) [1]. Air pollution has become a problem in the last few decades and it is caused by a number of different factors including air conditioners, aerosols, the burning of fossil fuel and natural environmental changes such as volcanic activities. When sulphur dioxide and nitrogen oxide are released into the atmosphere, these gases mix with the moisture in the air to form nitric acid and sulphuric acid and return to earth in the form of acid rain (Sharon and Kenneth, 1994) [14]. When acid precipitation falls, it can affect forests, field, gardens and aquatic plants. It can also affect paintings on buildings, erode limestone structures and sculptures, kill or dwarf trees, and reduce food crop yield (Kidd and Kidd, 2006) [10]. It also reduces soil fertility and contaminates drinking water sources (Tom, 2004) [16].

The effect of acid deposition on higher plants arises in two ways- either through foliage or through roots. The symptoms include direct damage to plant tissues (especially roots and foliage), reduced canopy cover, crown die back and whole tree death (Tomlinson, 1983). Leaf is the most sensitive organ to pollutant damage. It was found that acid rain caused anatomical alterations in the leaves of tropical species, seedlings and sapling of *Spondias dulcis* Forst. F., *Mimosa artemisiana* Heringer and Paula and *Gallesia integrifolia* (Sant Anna-Santos *et al.,* 2006) [13]. The susceptibility of plants to acid rain has been reported to vary greatly with plant species. Information available on the effects of simulated acid rain (SAR) on crop plants in India revealed that *Triticum aestivum* L. (wheat) variety would be susceptible to acidic precipitation (Wood and Bormann, 1975) [19]. In corn, Banwart *et al.,* (1987), reported cultivar difference in response to acid rain but observed no significant effect on grain yield down to pH 3.5. Acid rain has negative effects on seed germination of rice, wheat and grapes. It also inhibits reproduction of these plants (Huang *et al*., 2005) [7]. Kaya *et al*., (2005) [8], Wyrwicha and Sklodooska (2006) [20], reported that acid rain cause decline in the health and growth of trees. Chehragani *et al.,* (2007) [4], reported that acid rain has a detrimental effect on the developmental stages of ovules and seed protein in bean plants.

The study seeks to investigate the effects of simulated acid rain on the growth, yield and mineral nutrient relations of *Solanum lycopersicum* at varying level of acidity

2. Materials and Methods

2.1 Planting Procedure

The experiment was conducted in the screen house of the Department of Plant Biology and Biotechnology, Faculty of Life Sciences, University of Benin. Seeds were planted directly into experimental pots (16cm x 16cm) with 6 perforations made at the bottom with a 2mm diameter nail. Three viable seeds of *S. lycopersicum* were sown into loam soil mixed with farm yard manure at a depth of 3cm. The seedlings were watered and grown for three weeks after which thinning were carried out to reduce the plant to one per pot. The plants were there after grown for six weeks before treatments commenced. Each pH treatment had four replicates and was arranged in a completely randomized design (CRD).

Simulated acid rain was sprayed to the planted *S. lycopersicum* plants twice weekly for six weeks according to their pH values of 2.0, 3.0, 4.0, 5.0, and 5.6 (control). The solutions were applied using a medium size pressurized sprayer on the plants. The plants grew for six weeks before the experiment was terminated.

2.2 Preparation of Simulated Acid Rain

The acids used were an acidic mixture of concentrated sulphuric acid (H_2SO_4) and concentrated nitric acid (HNO3) in 3:1 ratio. The acidic solution was then diluted using distilled water with a Digital Hanna pH meter to get the desired pH (2.0, 3.0. 4.0, 5.0 and 5.6).

2.3 Data collection

Several parameters were used in assessing the growth and productivity of the plant. The height of shoot of the plants from the soil level to the top of the plant stems were measured using a meter rule. The measurements were taken weekly from the week acid spraying commenced to day of harvest. The number of leaves was determined by counting. The stem girth was determined with the aid of the vernier caliper. The Chlorophyll content index of the leaves was measured using the Apogee chlorophyll content meter CCM-200 plus. Measurement was done by holding down the arm of the sample head on the intact leaf until a beep was heard. The chlorophyll content was displayed on the screen of the device. Elemental analysis was carried out at the Central Analytical Laboratory, Nigerian Institute for Oil Palm Research, NIFOR to determine the level of N, P, K, Ca, Mg, Na, and Fe in the leaves of *C. frutescens.* Ca, Mg, and Fe, content were determined with Atomic Absorption spectrometer, bulk Scientific VGP 210. Na and K was determined using flame photometer while P and N were determined using colorimetric method.
The fresh and dry weights were determined after six weeks of treatment following the method of Hunt (1990).

2.4 Statistical Analysis

Data obtained were subjected to analysis using the Statistical Package for Social Sciences, Version 20.0. Treatment means were separated using the Duncan's multiple range test.

3. Results

The results on the plant height and number of leaves are presented in Figure 1 and 2 respectively. There was a significant decrease in the plant height and leaf number with increasing acidity levels. The plant had the highest plant height and number of leaves significantly higher ($p<0.05$) at the control (pH 5.6) compared to the other SAR treatments.

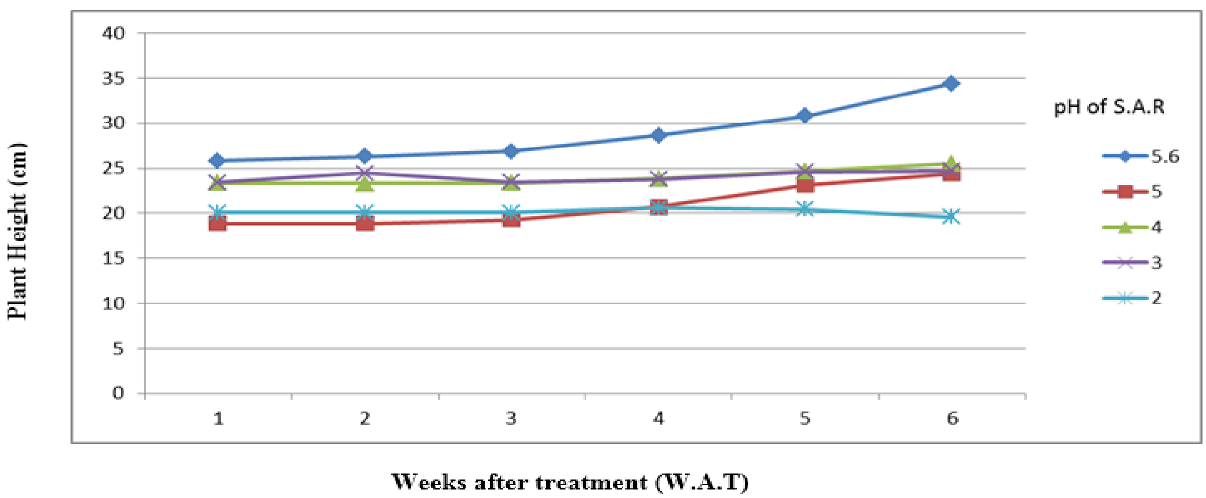

Fig1: Effects of simulated acid rain on plant height of *Solanum lycopersicum*

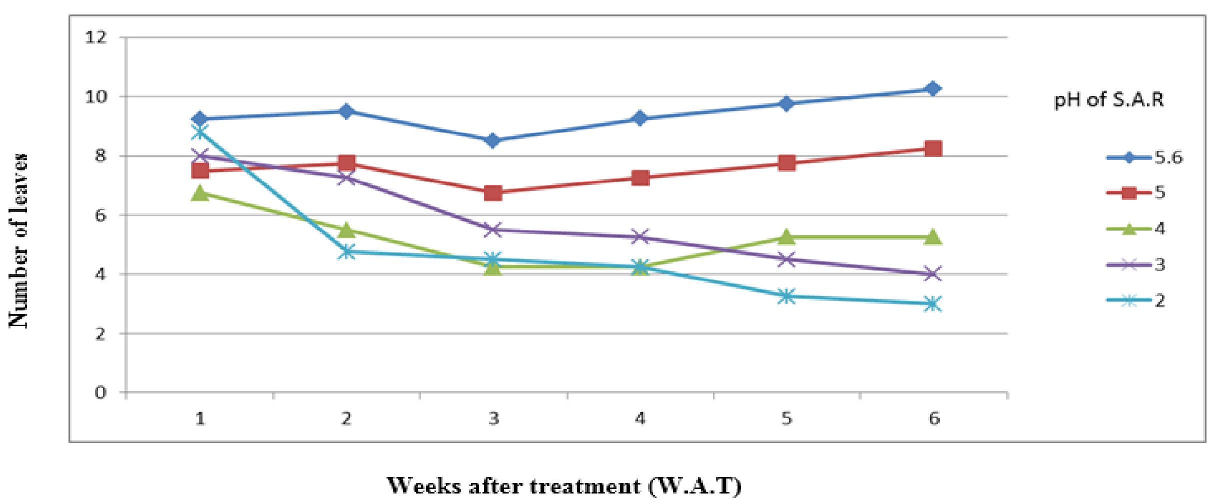

Fig 2: Effects of simulated acid rain on the number of leaves of *Solanum lycopersicum*

The results on the stem girth, fresh and dry weight biomass and chlorophyll content index are presented in Table 1, 2 and 3 respectively. There was a significant decrease in all parameters with increasing acidity levels.

Table 1: Effect of simulated acid rain (SAR) exposure at different pH on the stem girth of *Solanum lycopersicum.* Results are mean of 4 replicates ± S.E

	Control 5.6	5.0	4.0	3.0	2.0
Before exposure	0.32±0.25	0.32±0.25	0.25±0.28	0.17±0.04	0.17±0.47
After exposure	0.37±0.04	0.27±0.04	0.25±0.02	0.17±0.04	0.17±0.47

Table 2: Effect of simulated acid rain (SAR) on the Fresh and Dry weight of *Solanum lycopersicum.* Results are mean of 4 replicates ± S.E

Treatment pH	Fresh weight (g)	Dry weight (g)
Control (5.6)	18.97±2.13	6.05±0.82
5.0	17.72±1.48	5.87±0.65
4.0	6.05±1.22	1.12±0.49
3.0	5.25±0.05	0.77±0.11
2.0	4.37±0.95	0.77±0.16

Table 3: Effects of simulated acid rain (SAR) exposure at different pH on chlorophyll content index (CCI) of *Solanum lycopersicum*

pH of SAR	Chlorophyll content index (CCI)
5.6	11.57±1.88
5.0	9.55±1.22
4.0	7.55±1.65
3.0	5.95±1.65
2.0	5.65±1.91

Table 4: Nutrient accumulated in the leaves of *Solanum lycopersicum* treated with simulated acid rain

pH of SAR	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)
5.6	3.26	0.62	1.83	2.95	1.50	0.22	0.82
5.0	3.13	0.44	1.62	2.45	1.29	0.18	0.64
4.0	2.58	0.34	1.47	2.22	0.86	0.18	0.41
3.0	2.45	0.51	1.19	2.20	0.34	0.15	0.35
2.0	1.85	0.15	1.10	1.79	0.55	0.10	0.12

Morphological changes were observed throughout the period of the experiment. Table 5 shows the effects of simulated acid rain on the morphology of *S. lycopersicum*

Table 5: Morphological observation on the growth of *Solanum lycopersicum* treated with simulated acid rain

pH treatment	Observed effects
5.6 (control)	Plant had good growth.
5.0	Plant had good growth but older leaves showed signs of chlorosis.
4.0	Chlorosis, leaf deformation and necrotic lesions were noticed but plant showed good growth.
3.0 and 2.0	Necrotic lesions, leaf deformation was observed. Plant was stunted.

4. Discussion

The results obtained from this study shows that the higher the acidity of simulated acid rain treatment, the more adverse the effects were on the plant growth. This might be due to inhibition of cell division (Dwivedi *et al.*, 2007) [6]. Figure 1 and 2 showed the effect of simulated acid rain (SAR) exposure at different pH on plant height (cm) and leaf number of *Solanum lycopersicum.* The results indicated that under the stress of simulated acid rain, the shoot height and number of leaves decreased with the declining pH value of acid rain, which affects the terminal buds of the plant. This is in agreement with the work of Dunsun *et al*, (1998). Size of the leaves also decrease due to thinner mesophyll cells. Reduction in leaf size conforms to observation of Liange *et al*., (2008).

The morphological changes observed in this experiment (necrosis, chlorosis and deformation of leaf) is in accordance with the study of Dursun *et al*., (2002) [5] and Odiyi and Bamidele, (2013) [11]. It can be deduced from Table 1, that the control had the highest stem girth before and after exposure compared to pH 3.0 and 2.0 which had the least stem girth. Decrease in stem girth was proportional to increasing acidity as observed in Table 1. The result accords with earlier result of Tong and Liange, (2005) [17]. Decrease in biomass (fresh and dry weight) of *Solanum lycopersicum* was correlated to increasing acidity as observed in Table 2, which is in agreement to the findings of Banwart *et al.*, (1988) [3]. Due to increase in acidity, the growth of the plant was hampered and the biomass reduced (Arti *et al.*, 2010) [1]. It was inferred from Table 3 that the higher the acidity, the more the leaf chlorophyll content was inhibited. Plants treated with the lowest pH 2.0 had the lowest chlorophyll content index value (5.65) while the control treatment had the highest chlorophyll content index value (11.57). The difference was not significant when subjected to statistical analysis. The reason for this decrease in chlorophyll value was due to the aggregation of H^+ ions in the plant tissue displacing magnesium ions in the chlorophll molecule thereby retarding the chlorophyll pigment by converting chlorophyll to pheophytin molecule, which cannot carry out photosynthesis. This result was in agreement to the result of Arti *et al.*, (2010) [1]. Photosynthetic rate also decreased which might be due to reduction in leaf size or chlorophyll content (Huang *et al.*, 2005) [7].

The effect of pH from simulated acid rain on the mineral nutrient content of leaves of *Solanum lycopersicum* was determined at harvest. The elemental analysis result (Table 4) reveals loss of nutrient from plant leaves as pH increased. Nutrient such as Nitrogen (N), Potassium (K), Magnessium (Mg), Phosphorus (P), Iron (Fe) and Calcium (Ca) were lost from treated *Solanum lycopersicum* leaves. The reason for the nutrient leaching was due to the sulphate and nitrate ions (negatively charged) in the acid rain acting as inhibitors which allows positive ions to leached out of the soil. Nitrogen is an essential macronutrient needed by all plants to thrive. It is an important component of many structural, genetic and metabolic compounds in plant cells. It is also one of the basic components of chlorophyll, the compound by which plants use sunlight energy to produce sugar during the process of photosynthesis. The control plant with pH 5.6 had the highest nitrogen availability which indicates that there was high photosynthetic activity compared to the plant with the lowest pH 2.0 value, in which the nitrogen composition was the lowest, it show that photosynthetic ability was reduced. Available Fe in the leaves shows a positive increase for the control plant and Iron is needed to produce chlorophyll, hence its deficiency causes chlorosis, and leaf chlorosis will compromise the photosynthetic capability of plants. At pH 2.0, *Solanum lycopersicum* had a value of 0.12ppm as compared to control plants that had a value of 0.82ppm which is in agreement to the findings of Paparozzi and Tukey, (1986). According to Starr (2006), acid rain generally weakens plants such that they become more susceptible to damage from insects, disease, drought or environmental stress

Conclusion

It is evident from this study that simulated acid rain (SAR) treatment decrease the growth and mineral component of the test plant. The plant showed reduced growth with increasing acidity due to a reduction of photosynthesis as a result of chlorosis, necrosis and leaf abscission. It is important therefore, that preventive and control measures be taken to reduce the effects of acid rain on crop plants. There is also need to determine the sensitivity of other crops in Nigeria to the effects of SAR.

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