

Effects of Simulated Acid Rain on Growth and Development of a Monocot (zea mays l.) and a Dicot (phaseolus vulgaris l.) Cultivated in Sabon Layi, Kaltungo Local Government Area, Gombe State, Nigeria

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ABSTRACT

Acid rain is a major environmental concern that refers to precipitation such as rain, snow, or fog, with a pH level lower than the normal range, resulting from the accumulation of atmospheric pollutants. The aim of this research is to investigate and compare the effects of simulated acid rain on the growth and development of selected monocot (maize) and dicot (beans) species, with the specific objectives of evaluating the effect of simulated acid rain on growth parameters of maize and beans and compare the tolerance of monocot and dicot plants to acid rain stress. Simulated acid rain was prepared by diluting sulfuric acid (H₂SO₄) and nitric acid (HNO₃) in distilled water to achieve the desired pH levels. forty (40) experimental pots were filled with loam soil mixed with farm yard manure. Two viable seeds of maize and beans were sown into each experimental pots at a depth of 3cm, after three weeks, seedlings were thinned to reduce the plant to one per pot. Simulated acid rain was sprayed to the plants twice weekly for eight weeks according to their pH values of 2.5, 3.5, 4.5, and 7.0 control. The plants grew for eight weeks before the experiment was terminated. The research findings revealed the effects of monocot and dicot roots, shoots and leaves biomass and length of dicot plants responded more adversely to acid rain compared to monocot and the response decreased with decreasing pH. All parameters in monocots show significant differences across pH treatments ($p < 0.05$), only Root length in dicots shows no significant difference across pH treatments ($p = 0.2332$). In conclusion, simulated acid rain significantly reduced growth parameters in both species, with Phaseolus vulgaris showing greater sensitivity than Zea mays.

Keywords— Simulated acid rain; plant growth; Zea mays; Phaseolus vulgaris; soil acidity; plant physiology

I. INTRODUCTION

Acid rain is a major environmental concern that has drawn significant attention from researchers and policymakers worldwide. Acid rain refers to precipitation, such as rain, snow or fog, with a pH level lower than the normal range of 5.6 due to the presence of certain pollutants in the atmosphere [2]. These pollutants, primarily sulfur dioxide (SO₂) and nitrogen oxides (NO_x), are primarily emitted from the combustion of fossil fuels, such as in industrial processes and vehicle emissions.

The impact of acid rain on plant growth and development has been extensively studied. Plants are particularly vulnerable to changes in soil pH and the availability of essential nutrients [17]. Monocot and dicot plants, which are the two main groups of flowering plants, have distinct anatomical and physiological characteristics that may influence their response to acid rain [27].

Monocot plants, such as grasses and cereals, generally have a more fibrous root system and lack a specialized vascular cambium, which can make them more sensitive to changes in soil pH and nutrient availability [2]. Conversely, dicot plants, such as trees and many flowering plants, often have a more extensive taproot system and a specialized vascular cambium, which may provide them with a higher tolerance to acid rain [17].

Several studies have investigated the effects of acid rain on the growth and development of monocot and dicot plants. For example, a study by [25] found that the growth and biomass production of several monocot crop species, including corn and wheat, were significantly reduced when exposed to simulated acid rain. In contrast, a study by [10] reported that the growth of some dicot tree species, such as oak and maple, was less affected by acid rain, suggesting a higher tolerance in these plants.

The mechanisms by which acid rain affects plant growth and development are complex and involve various physiological and biochemical processes. Acid rain can influence the availability of essential nutrients in the soil, such as calcium and magnesium, and can also disrupt the plant's ability to absorb and transport these nutrients [17]. Additionally, acid rain can cause direct damage to plant tissues, leading to changes in photosynthetic rates, water balance, and other essential processes [27].

The deposition of acid rain can have significant and far-reaching effects on terrestrial ecosystems [4]. One of the primary impacts is on the soil, where the acidity can lead to the leaching of essential nutrients, such as calcium, magnesium, and potassium, from the soil matrix [1]. This nutrient depletion can impair the growth and development of plants, as well as disrupt the delicate balance of soil organisms and microbial communities [25].

In addition to soil effects, acid rain can also directly impact the foliage and physiology of plants. The acidic nature of the precipitation can damage plant cell membranes, interfere with nutrient uptake, and disrupt photosynthetic processes, leading to decreased growth, reduced biomass, and in severe cases, the death of the plant [25]. The sensitivity of different plant species to acid rain can vary significantly, depending on factors such as plant morphology, metabolic pathways, and stress response mechanisms [10].

Acid rain is a pressing environmental concern that has the potential to significantly impact on the growth and development of plants, which are the foundation of terrestrial ecosystems. While the effects of acid rain on plants have been extensively studied, there is a remaining notable gap in understanding the differential responses of monocotyledonous (Maize) and dicotyledonous (Beans) plants. Monocot and Dicot, exhibit distinctive anatomical and physiological characteristics that may influence their susceptibility to acid rain. Despite their importance in global agriculture, little is known about how these two groups response differently to acid rain exposure.

A. *Research Objectives*

1. To evaluate the effect of simulated acid rain on growth parameters of maize and beans.
2. To compare the tolerance of monocot and dicot plants to acid rain stress.

B. *Research Hypothesis*

H₀: Simulated acid rain has no significant effect on growth parameters of maize and bean plants.

II. MATERIALS AND METHODS

A. *Study location*

The study was conducted in Sabon Layi, Kaltungo Local Government Area, Gombe State, Nigeria. The Local Government location is between the coordinate's latitude 9°48'51"N and longitude 11°18'32"E. Kaltungo LGA covers an area of 881 sq/k and experiences two distinct dry and rainy season. The area is known for agricultural activities and serves as an ideal location for the study. The environmental conditions in area are typical of semi-arid regions, characterized by moderate rainfall and hot temperatures. Kaltungo LGA receives an estimated 1000 mm of precipitation annually, wind blows on average at 10 km/h.

B. *Preparation of Simulated Acid Rain*

The acids used were an acidic mixture of concentrated sulphuric acid (H₂SO₄) and concentrated nitric acid (HNO₃) in a 3:1 ratio. The acidic solution was then diluted using distilled water with a Digital Hanna pH meter to get the desired pH (2.5, 3.5, 4.5, and 7.0).

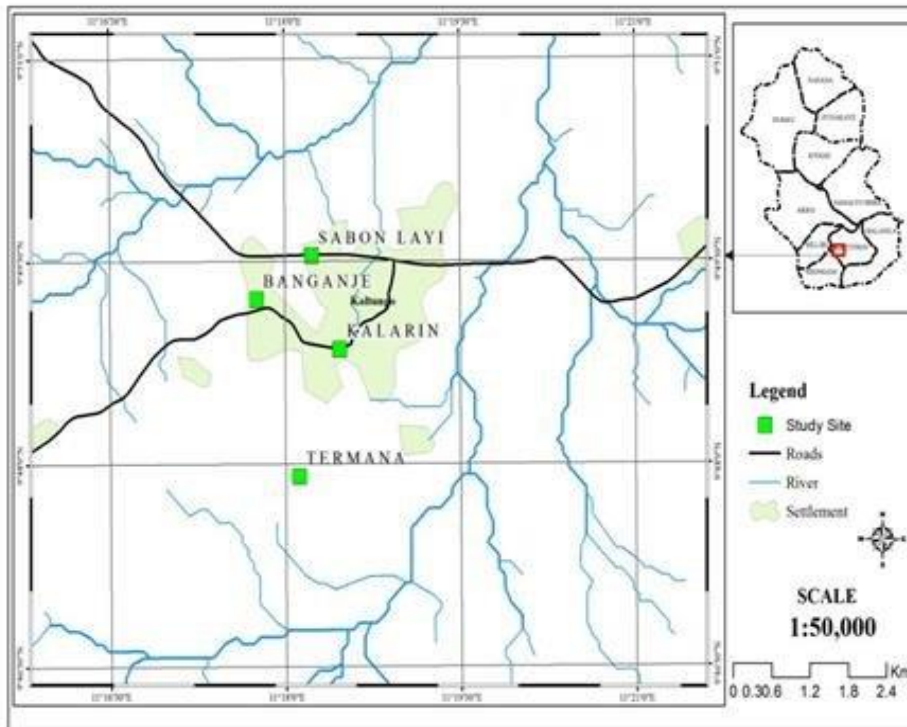


Fig.1: Map of Kaltungo Showing the Study Area

C. Planting Procedure

The experiment was conducted in the botanical garden of the Department of Science Laboratory Technology, School of Science and Technology Federal Polytechnic Kaltungo. The garden optimal temperature range between 30⁰c -39⁰c.

Forty (40) experimental pots (14cm x 14cm) with 8 perforations made at the bottom to reduce water lodge were filled with loam soil mixed with farm yard manure. Two viable seeds of maize and beans were sown into the experimental pots at a depth of 3cm. The seedlings were irrigated early in the morning every day. The seedlings grown for three weeks after which thinning were carried out to reduce the plant to one per pot. The plants were grown for four (4) weeks before treatments commenced. Each pH treatment had five replicates and was arranged in a completely randomized design (CRD) under exposure of sunlight.

Simulated acid rain was sprayed to the plants twice weekly for eight weeks according to their pH values of 2.5, 3.5, 4.5, and 7.0 control. The solutions were applied using a medium size sprayer on the plants. The plants grew for eight weeks before the experiment was terminated.

D. Data Collection

Several parameters were used in assessing the growth and productivity of the plant. These parameters include plant height, leaf area and biomass accumulation. These are important indicators of plant health and are expected to be affected by acid rain exposure.

Measurements of plant height were taken using a measuring tape from the apical bud to root cap, while biomass was assessed by harvesting and weighing the plants. Plants were oven-dried at 70°C until constant weight. Leaf area were measured using portable leaf area meter, and root length was measured using measuring tape after carefully uprooting the plants. All measurements were taken at the end of the eight week experimental period upon termination.

E. Data Analysis

The data obtained from this research was analysed using SPSS Statistical software package (version 16.0) and a one way and two-way Analysis of Variance (ANOVA) were used to compare pH effect on all growth parameters and effects of acid rain concentration on plant types (maize versus beans) respectively, at 0.05% level of significance. Statistical tool (mean and standard deviations) was used to summarize the results of five replicates.

III. RESULTS

Table 1: Result of effect of simulated acid rain on growth and development of selected monocot (maize) and dicot (beans).

Treatment	Fresh weight		Dry weight		Root length		Shoot length		Leaf length		Leaf Area	
	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot
Control	7.35	6.24	2.95	2.25	10.90	8.60	56.28	38.50	9.96	3.50	90.18	52.33
4.50	6.41	5.24	2.26	2.05	9.10	8.10	42.66	32.46	9.00	3.02	82.35	48.46
3.50	5.82	4.81	1.93	1.50	7.81	7.95	38.33	28.73	8.50	2.80	76.08	40.64
2.50	4.46	3.50	1.40	1.05	6.67	7.24	32.66	24.64	6.65	2.01	70.61	35.80
P-Value	0.0014	0.0008	0.0010	0.0006	0.0015	0.2332	0.0011	0.0045	0.0036	0.0010	0.0010	0.0011

Note: Each value is a mean of five replicates

A. Effect of SAR on Fresh Weight

In monocots, the control group had a mean fresh weight of 7.35 g. Under pH 4.50, fresh weight decreased to 6.41 g, followed by further reductions to 5.82 g at pH 3.50 and 4.46 g at pH 2.50 Fig.2. The statistical analysis confirmed a highly significant effect of pH on fresh weight in monocots (p 0.0014). Similarly, dicots exhibited a progressive decline in fresh weight from 6.24 g in the control to 5.24 g at pH 4.50, 4.81g

at pH 3.50, and 3.50 g at pH 2.50. This reduction was also statistically significant ($p = 0.0008$). These findings indicate that acidic conditions adversely affect water uptake and retention, with the most severe treatment (pH 2.50) causing the greatest reduction in fresh biomass for both monocot and dicot.

B. Effect of SAR on Dry Weight

Monocots dry weight declined from 2.95 g in the control to 2.26 g at pH 4.50, 1.93 g at pH 3.50, and 1.40 g at pH 2.50. This trend was statistically significant ($p = 0.0010$). For dicots, dry weight decreased from 2.25 g (control) to 2.05 g at pH 4.50, 1.50 g at pH 3.50, and 1.05 g at pH 2.50 Fig 3. The overall effect was highly significant ($p = 0.0006$). The consistent reduction in dry weight across both groups suggests that low pH impairs photosynthetic efficiency, nutrient assimilation, or both, leading to reduced organic matter accumulation.

C. Effect of SAR on Root Length

Monocots showed a steady decline in root length from 10.90 cm in the control to 9.10 cm at pH 4.50, 7.81 cm at pH 3.50, and 6.67 cm at pH 2.50. This reduction was statistically significant ($p = 0.0015$). The finding indicating that root elongation in monocots is highly sensitive to acidic pH. In dicots, root length decreased from 8.60 cm in the control to 8.10 cm at pH 4.50, 7.95 cm at pH 3.50, and 7.24 cm at pH 2.50 Fig 4. However, the p -value was 0.2332, which is above the conventional threshold for statistical significance ($p < 0.05$). This suggests value is not statistically significance.

D. Effect of SAR on Shoot Length

Shoot length reflects aboveground growth and is often correlated with overall plant vigor and photosynthetic capacity. In monocots, shoot length decreased markedly from 56.28 cm in the control to 42.66 cm at pH 4.50, 38.33 cm at pH 3.50, and 32.66 cm at pH 2.50. This decline was statistically significant ($p = 0.0011$). Dicots also exhibited a significant reduction in shoot length, falling from 38.50 cm (control) to 32.46 cm at pH 4.50, 28.73 cm at pH 3.50, and 24.64 cm at pH 2.50 Fig 5. ($p = 0.0045$). The pronounced reduction in shoot length under acidic conditions suggests that low pH disrupts cell elongation and division in aboveground tissues, possibly due to impaired nutrient transport or hormonal imbalances.

E. Effect of SAR on Effect of SAR on Leaf Length

Monocots showed a consistent decrease in leaf length from 9.96 cm in the control to 9.00 cm at pH 4.50, 8.50 cm at pH 3.50, and 6.65 cm at pH 2.50. The difference was statistically significant ($p = 0.0036$). In dicots, leaf length declined from 3.50 cm (control) to 3.02 cm at pH 4.50, 2.80 cm at pH 3.50, and 2.01 cm at pH 2.50 Fig 6. This reduction was also statistically significant ($p = 0.0010$). The significant reductions in leaf length across both groups indicate that leaf expansion is highly sensitive to pH stress, which may be

attributed to reduce turgor pressure, disruption of cell wall extensibility, or reduced availability of essential nutrients such as calcium and magnesium under acidic conditions.

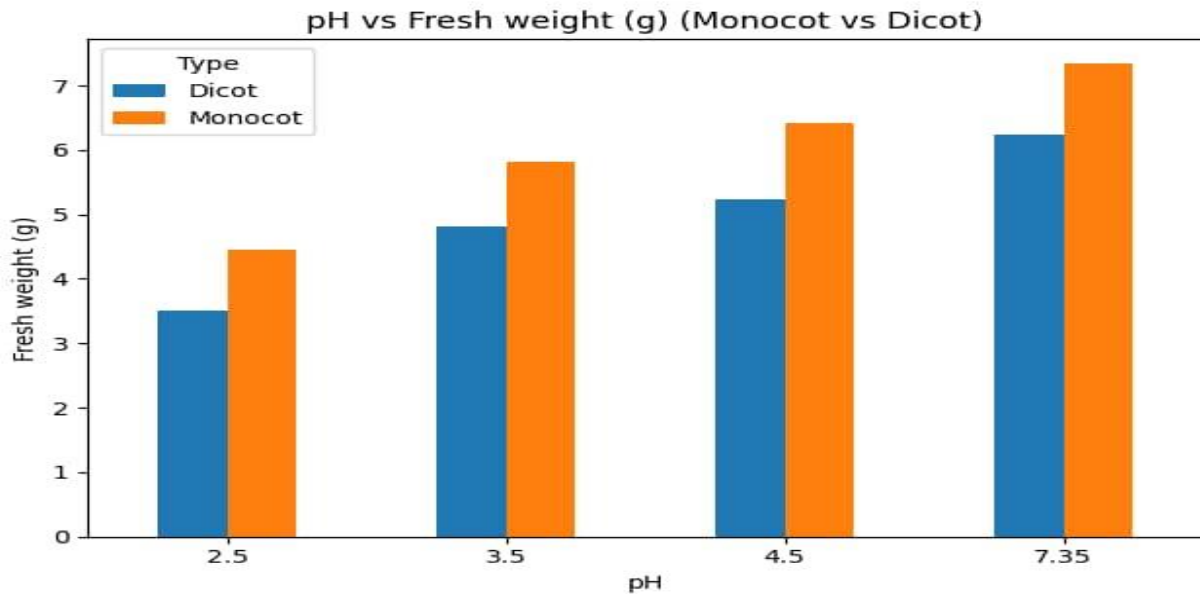


Fig. 2: Effect of simulated acid rain on fresh weight of maize (monocot) and beans (dicot). The values are mean of five replicates.

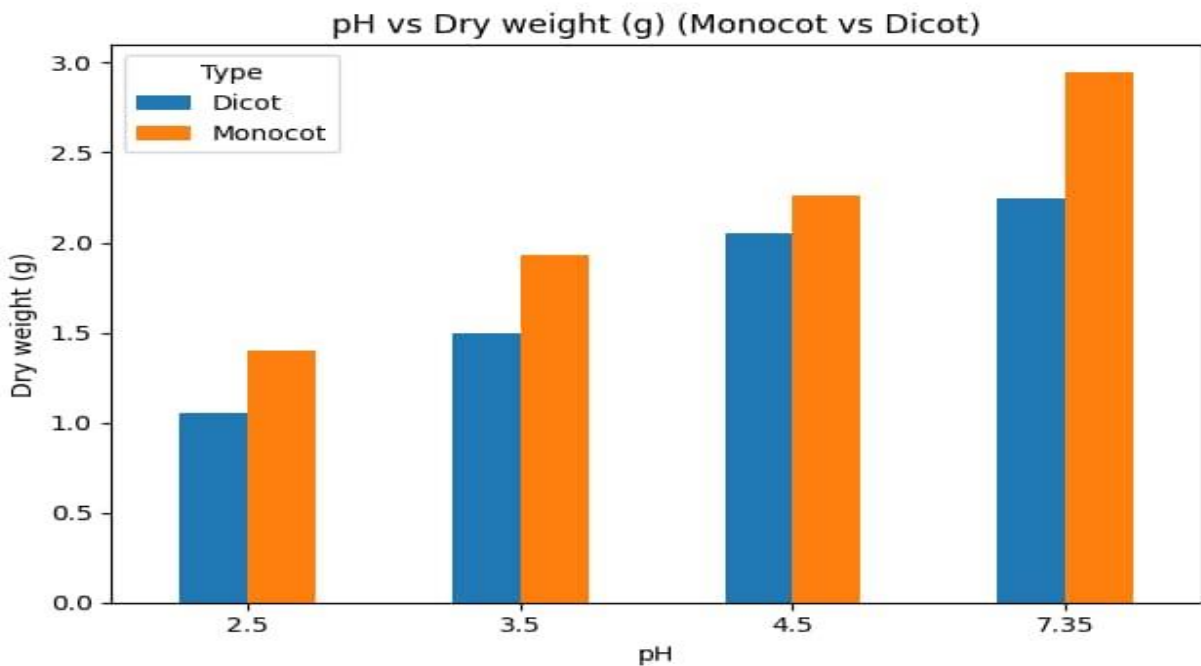


Fig. 3: Effect of simulated acid rain on Dry weight of maize (monocot) and beans (dicot). The values are mean of five replicates

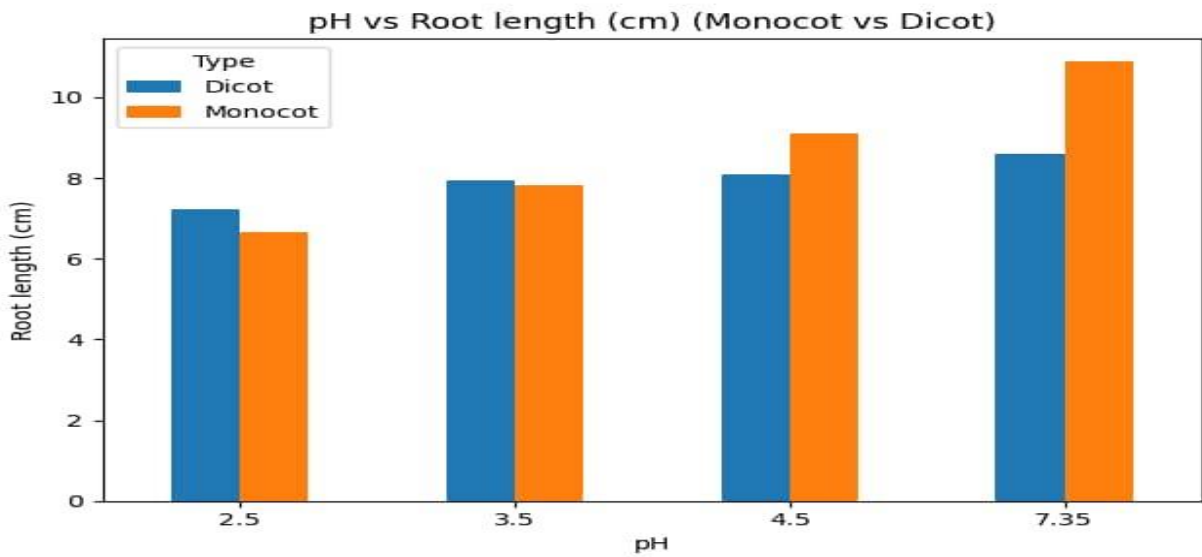


Fig. 4: Effect of simulated acid rain on root length of maize (monocot) and beans (dicot). The values are mean of five replicates

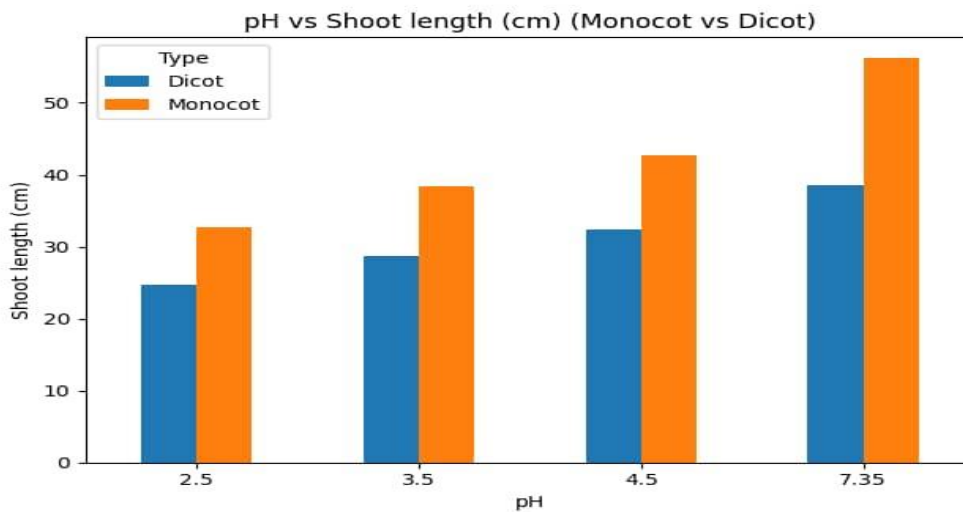


Fig. 5: Effect of simulated acid rain on shoot length of maize (monocot) and beans (dicot). The values are mean of five replicates

F. Effect of SAR on Leaf Area

In monocots, leaf area decreased progressively from 90.18 cm² in the control to 82.35 cm² at pH 4.50, 76.08 cm² at pH 3.50, and 70.61 cm² at pH 2.50. This trend was statistically significant (p 0.0010). Similarly, dicots showed a decline in leaf area from 52.33 cm² (control) to 48.46 cm² at pH 4.50, 40.64 cm² at pH 3.50, and 35.80 cm² at pH 2.50 Fig 7. With a significant overall effect (p = 0.0011).

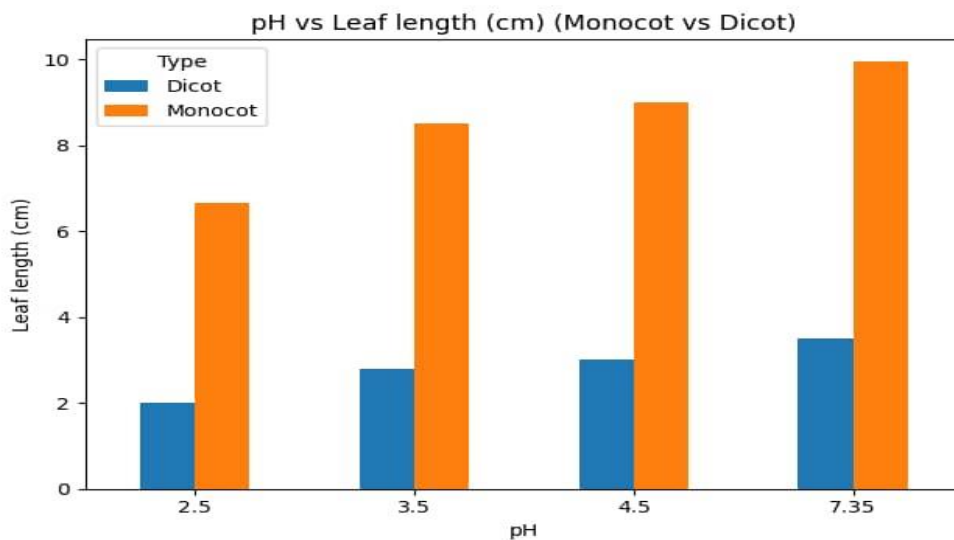


Fig. 6: Effect of simulated acid rain on leaf length of maize (monocot) and beans (dicot). The values are mean of five replicates.

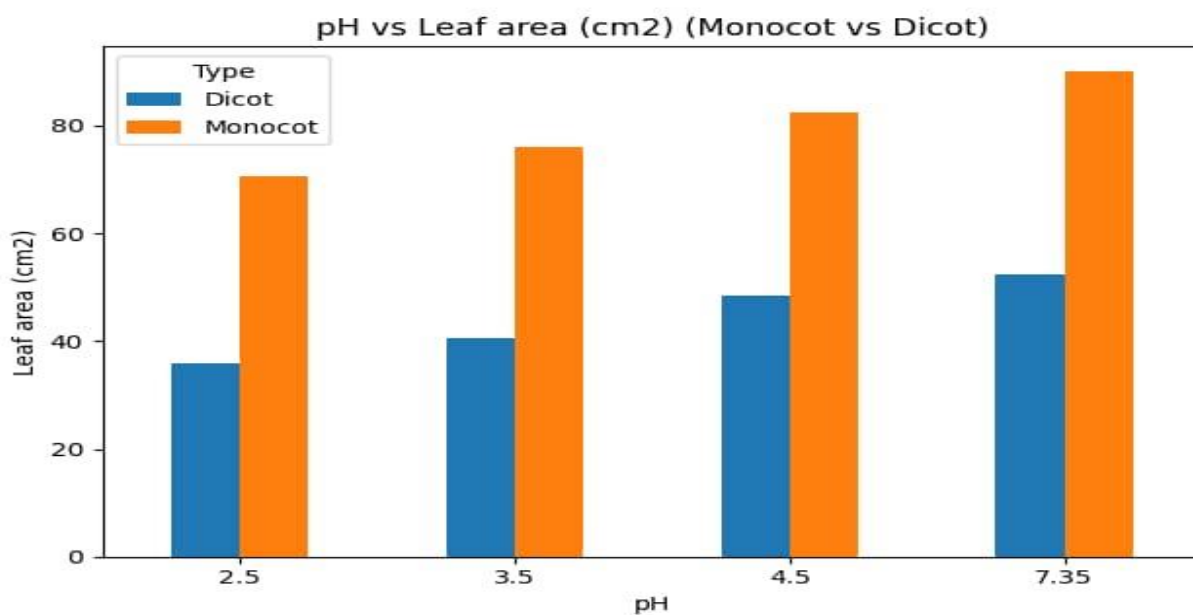


Fig. 7: Effect of simulated acid rain on leaf area of maize (monocot) and beans (dicot). The values are mean of five replicates

IV. DISCUSSION

The results obtained from this research show that the higher the acidity of simulated acid rain treatment, the more adverse the effects on the plant growth. This might be due to inhibition of cell division. The decrease in biomass (fresh and dry weight) of maize (monocot) and beans (dicot) was correlated to

increasing acidity which is in agreement to the findings of [2]. Due to increase in acidity, the growth of the plant was hampered, and the biomass reduced [1]. The finding of [29] in pea plant and [24] in *Trifolium alexandrinum* plants are all correlated with this research finding. Pragati and [16] reported that root fresh weight decreased as the pH of the acid rain increase.

The significant reduction in fresh and dry weights, particularly at pH 3.50 and 2.50, is a strong indicator of impaired nutrient uptake and increased nutrient loss. Under low pH conditions, the increased concentration of H^+ ions in the soil solution displaces essential cations such as K^+ , Ca^{2+} , and Mg^{2+} from the negative exchange sites on soil colloids. These cations are then highly susceptible to leaching below the root zone, making them unavailable for plant uptake [4]. The observed decrease in dry weight is especially critical, as it represents a reduction in the accumulation of structural biomass, a process that heavily depends on a balanced supply of macronutrients. The reduced root length at low pH further compromises the plant's ability to forage for the remaining nutrients in the soil, creating a positive feedback loop of nutrient deficiency [2].

The decrease in root length was proportional to increasing acidity as observed in Table 1. The result accords with earlier result of [13]. Which is in agreement with the findings of [2], rice [23], wheat [21], rice [26], pea [29], mash [8], fodder crops [24], *Zinnia elegans* [16], barley [15], *Vigna unguiculata* [5] and wheat [11]. The decrease in root length might be due to accumulation of acid in cell sap of root tissues which restrict the free movement of nutrients from source to sink.

The reduction in leaf length and leaf area, which correlates with the overall decrease in fresh weight, is often a visual symptom of chlorophyll degradation. Low pH conditions, especially those induced by acid rain or acidic soil, which lead to an increased availability of phytotoxic metals like Al^{3+} , Mn^{2+} , and Fe^{2+} [16]. The resulting chlorophyll damage reduces photosynthetic efficiency, which directly limits the production of assimilates (carbohydrates) needed for leaf expansion and biomass accumulation. This explains the progressive decline in leaf area from 90.18 (control) to 70.61 (pH 2.50) in monocots and from 52.33 to 35.80 in dicots.

Leaf Length, Shoot Length and Leaf Area of both maize (monocot) and beans (dicot) recorded significance decrease with increase pH, this in agreement to the result of [1]. Photosynthetic rate decreased which might be due to reduction in leaf size or chlorophyll content and a finding of [7]. Similar observations are reported in different crops species including soybean [12], *Perilla frutescent* [3], wheat [21] and *Trifolium alexandrinum* [24].

The significant reduction in shoot and root lengths at low pH treatments suggests a systemic inhibition of metabolic processes, including the activity of key enzymes. H^+ toxicity can alter the cytoplasmic pH, which destabilizes the three-dimensional structure of enzymes, rendering them inactive. Stomatal damage was not directly measured in this study, its impact is reflected in the growth data. The significant reduction in leaf area and fresh weight can be partly attributed to compromised stomatal function. Acidic conditions can directly damage guard cells or disrupt the hormonal signaling pathways (e.g., abscisic acid) that control stomatal aperture. Stomatal damage typically results in one of two outcomes: uncontrolled water loss (desiccation) due to stomata that fail to close, or a permanent closure to prevent further water loss.

V. CONCLUSION

It is evident from this study that, simulated acid rain significantly reduced growth parameters in both species, with *Phaseolus vulgaris* showing greater sensitivity than *Zea mays*. Therefore, it is important, policy makers to provide preventive and control measures to reduce the effects of acid rain on plants. There is also the need to determine the sensitivity of other crops to the effects of SAR.

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