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Effect of simulated acid rain on growth and micronutrient uptake of okra (*Abelmoschus esculentus*) on coastal plain sands in Abia State, South-eastern, Nigeria

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ABSTRACT

The study was conducted in April, 2019 at Umudike to examine the impact of simulated acid rain (SAR) and frequency of SAR spray on growth and micronutrients content of okra (*Abelmoschus esculentus* (L.) Moench) in an ultisol at Umudike. The treatments consisted of three (3) pH levels: Coca-cola solution (pH 2.7) and SAR (pH 3.5 and 5.5) as well as control (water) and; three (3) frequency of foliar spray at 1, 2 and 3 day weekly, arranged according to their respective pH values and spray treatments in a completely randomized design (CRD) replicated three times. Plant leaves were analysis for micronutrients (Cu, Fe, Mn and Zn) content. The result shows that, under the stress of SAR and frequency of SAR application, growth parameters measured; leaf number, shoot height and leaf area were significantly reduced, compared to the control treatment. Nutritional analysis of the leaves also revealed that, the content micronutrients in okra, increased with declining pH value of AR and frequency of application, from pH 5.5 to pH 2.7. Coke solution (pH 2.7) and three (3) days per weekly application of SAR gave the highest reduction in plant growth parameter in Okra but, had higher increased in micronutrients content, respectively. Further result showed that okra (*Abelmoschus esculentus* (L.) Moench) is resistant to SAR from pH ≥5.5 in terms of growth and nutritional values.

1.0. Introduction

Acid rainfall (AR) is a form of wet deposition that has been acidified when pollutants, such as oxides of sulphur and nitrogen, contained in power plant emission, factory smoke and car exhaust, react with the moisture in the atmosphere (Kita *et al*., 2004), with elevated levels of hydrogen ions (low pH) (Prashant, 2010). The processes of acid rains (AR) and other types of acidic deposition, such as acid snow, hail, dew, and fog, form when the emissions of SO_2 and NO, react with water molecules in the atmosphere to produce acids (Chesapeake, 2013). These pollutants (SO_2, NOx), once released into the atmosphere, can be converted chemically (under the influence of sunlight and moisture) into secondary pollutants such as sulphuric acid (H_2SO_4) and nitric acid (HNO_3), which fall as acid rain (Li and Gao, 2002).

Plants exposure to Acid rainfall (AR) results in characteristic foliar injury symptoms, modified leaf anatomy, structural changes in the photosynthetic pigment apparatus and a decrease in chlorophyll a and b contents (Sant' Anna-Santos *et al*., 2006). Exposure to simulated acid rain (SAR) alters the ability of plants to take in CO_2 for photosynthesis and consequently inhibits the production of glucose (Sunita and Sharad, 2013). Singh and Agrawal (2001) noted that the shoot and root lengths, leaf areas, and total biomass or yield of two varieties of wheat declined significantly at or below pH 4.0 and concluded that SAR had a significantly negative effect on wheat. Compared with other crops such as cereals, root and tubers, *etc*, vegetables crops are expected to be more sensitive to AR (Meng *et al.*, 2011). Based on the field investigations and experimental results, the effects of AR on vegetables include poor seed germination and seedling growth, leaf injury (Meng *et al.*, 2011), interference with normal metabolism (Johnston *et al.*, 1986: Khan and Shikha, 2004), growth and yield (Dubay and Allen, 1987) as well as nutritional quality (Nduka, et al., 2008). There are several mechanisms by which AR influences plant growth, as by direct foliar injury or indirect by affecting root's soil-water relations (Prashant, 2010; Chesapeake, 2013).

Okra is a very sensitive crop to high concentrations of acid levels like many other vegetable plants. Foliar applications of SAR have been shown to result in significant reductions in *Abelmoschus esculentus* yield and quality (Eguagie *et al.,* 2016). *Abelmoschus esculentus* was therefore chosen for this experiment since, Lee *et al.* (1981) demonstrated an increase in its productivity with acidic rainfall with a pH <4.5, while Eguagie *et al.*, (2016) under greenhouse and agronomic field conditions, showed that, foliar injury was accompanied by a decline in growth and yield due to low pH levels of simulated acid rain (SAR <4.5). However, field studies reported by Odiyi and Bamidele (2014), Odiyi and Eniola (2014), and Milton and Abigael (2015) revealed that simulated AR caused reduction in plant growth and yield of cassava, cowpea and okra, respectively. This more or less supports the preceding reports.

The adverse effects of acid rain which include; chlorosis, necrosis, early senescence and stunting have been reported by Kausar *et al.*, (2005) and Bamidele and Eguagie, (2015), Also, Exposure of plants to AR which resulted in characteristic foliar injury symptoms, modified leaf anatomy, structural changes in the photosynthetic pigment apparatus and a decrease in the chlorophyll concentrations were reported by Chesapeake, (2013), Stoynora and Velikova, (2004), Sant' Anna-Santos *et al*., (2006).

Acid rain deposition have also been reported to cause a reduction in soil fertility as well as leaching of metals which may lead to depletion of essential nutrient minerals from leaves and soil (Butnariu and Samfira, 2013; Eguagie *et al.,* 2016). With improper functioning of leaves, the growth of tree crops is retarded, resulting in loss of leaves and stunted growth.

Little or no information is currently available concerning the effects of simulated acid rainfall and frequency of foliar spray on growth and nutrient content of Okra in Umudike, South-eastern Nigeria. The study therefore, examined the impact of SAR and frequency of foliar spray on growth performance and micronutrient content of okra (*Abelmoschus esculentus* (L.) Moench) on a coastal plain sands soil in south-eastern Nigeria.

2.0. Materials and methods

2.1. Description of the study area

The study was conducted in a greenhouse environment from April to September, 2019 in Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria (Latitude 05^0 48' 21' N and Longitude 07^0 53' 94' E), with an altitude of 116 meter above sea level., from the site is level to gentle sloping. The study area falls within the tropical rain forest with mean annual rainfall of 2200 mm, distributed over 9 months in bimodal rainfall pattern, with 5 months of dry season and short dry period popularly called August break. The relative humidity varies from 84% to 87% while, monthly minimum air temperature ranged from 20^0C to 24^0C and the monthly maximum air temperature ranged from 28^0C to 35^0C (NRCRI, 2018).

2.2. Preparation of simulated acid rain (SAR)

The simulated acid rain was formed from a mixture of concentrated sulphuric acid (H_2SO_4) and concentrated nitric acid (HNO_3) in a ratio of 3:1. A 60 ml of sulphuric acid and 20 ml of nitric acid were measured with the measuring cylinder into a conical flask containing distilled water and was made up to 2 liters. The acidic solutions were then calibrated using concentrated NH_4OAc solution and distilled water with a Deluxe pH meter to get the desired pH (3.5. and 5.5), Coca-cola solution contains phosphoric acid with a pH of 2.7 (Eteng *et al.,* 2014) and cross checked with pH meter. There was a control which comprised no AR.

2.3. Treatments and experimental design

Okra seeds (Var. Clemsor spineless) produced by Premier Seeds in Nigeria, were obtained from National Seed Council Umudike, Abia State, Nigeria. The soil used for the experiment was obtained from from the 0-20 cm soil depth in the Michael Okpara University of Agriculture Farm.

Four (4) levels of treatments consisted of three (3) pH levels: one Coca-cola solution (pH 2.7) and two SAR (pH 3.5, 5.5) as well as a control (no treatment) and three (3) frequency of SAR application applied at 1, 2 and 3 times per week. A total of twelve (12) treatment combinations, arranged according to a completely randomized design (CRD) replicated three times.

2.4. Planting and foliar application of SAR procedures

Before planting, the okra seeds (Var. Clemsor spineless) were soaked for 12 hours in order to soften the seed coat and hasten germination. Three viable seeds of *Abelmoschus esculentus* were sown in each plastic pot and germination was achieved after 3 days of planting. Thinning was done after 14 days of planting, leaving two plants per pot of 10 liters capacity. The plants were thereafter grown for three weeks before the acid treatments commenced.

After three (3) weeks of planting, 10 ml each of SAR and Coca-cola solutions were foliar sprayed on the okra leaves at a frequency of once (1), twice (2) and thrice (3) weekly according to their pH values, respectively, using a hand-held medium size pressurized sprayer to mimic natural rainfall. The acid solution application was carried out fortnightly following the methods of Lal and Singh (2012) and Milton and Abigael, (2015). Th study lasted for eight weeks before the experiment was terminated.

2.5. Laboratory analysis

100g of the soil samples collected and used for the were airdried, sieved with a 2 mm sieve and stored for some chemical analysis. The soil chemical properties were analyzed according to standard procedures using the methods of IITA, 1979 and a modifies version of Udo *et. al.* (2009). The initial soil properties used for the pot experiment showed that, the soil was sandy loam, strongly acidic with pH of 5.16. Organic carbon was 7.14 g kg^{-1} with total N of 1.34 g kg^{-1} and available P of 6.12 mg kg^{-1}. Exchangeable bases were 2.25, 1.37, 0.26 and 0.14 cmol kg^{-1} for Ca, Mg, K and Na, respectively. The values of the available micronutrients determined by AAS were, 0.8, 6.8, 5.40 and 2.00 mg kg^{-1} for Cu, Fe, Mn and Zn, respectively.

The extraction of available soil Cu, Fe, Mn and Zn and their nutritional values in okra plants were determined according to standard procedures using the atomic absorption spectrophotometer (AAS), as described by Meng *et al* (2011). The values of the available micronutrients determined were, 0.8, 6.8, 5.40 and 2.00 $mgkg^{-1}$ for copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), respectively while, the nutritional values in okra plants are presented accordingly in Table 2.

The elemental analysis for nutritional values of okra was carried out at the National Soil Plant, Fertilizer and water Laboratory, Umudike. Dry okra leaves were ground and milled to pass through 1 mm sieve. The ground samples were subjected to tissue analysis to determine content of Cu, Fe, Mn and Zn using the atomic absorption spectrometer (AAS).

2.6. Determination of growth components

Data on growth parameters were measured and recorded at 3, 5 and 7 weeks after planting (WAP), respectively. The okra plants flowered but, there were no fruits as most of the plant except for the control had almost shaded their leaves by 8WAP when the experiment was terminated. Several parameters were used in assessing the growth and productivity of the plant.

The plant height was determined from the soil level to the tip of the tallest leaf using a meter rule. The leaf number per plant was determined by counting, while the leaf area (LA) was determined by multiplying the length and width of the leaf. The measurements were taken fortnightly at 3WAP, 5WAP and 7WAP after the application of the SAR.

2.7. Statistical analysis

The data generated from the laboratory analysis and field experiment were subjected to statistical analysis of variance (ANOVA) and significant means were separated using Fishers' least significant different (FLSD) at 5% level of probability.

3. 0. Results and discussion

3.1. Effects of simulated acid rain and frequency of application on some phenological growth parameters of okra

Plant height: Figure 1 (A & B), shows the effects of SAR and frequency of SAR application on the plant height of *A. esculentus* @ 3, 5 and 7 WAS, respectively. Considering the effect of SAR (Fig. 1A), there was a significant decline in shoot heights from 3 to 7 WAS as concentrations decreased in pH value. The mean tallest plants were recorded at control (29.89 cm) followed by pH 4.5 with 26.70 cm and pH 2.7 produced the least plant height of 22.59 cm. Considering the effect of frequency of SAR application (Fig. 1B), there was equally significant reduction in shoot heights from 3 to 7 WAP as the frequency of SAR application increases from once to thrice a week. The mean tallest plant was recorded at an application of once a week (28.95 cm), while the mean shortest plant height of 17.47 cm was observed at an application of 3 times a week. With regards to the interaction effects (Table 1), higher plants were observed in the control pots with increase in growth from 3 to 7 WAP followed by a sequential reduction of the plants height as the concentrations decreases in pH value, as well as the increases in frequency of application from once weekly to thrice weekly, respectively.

From the results obtained, it was observed that the higher the acidity and frequency of application, the more the plant height of okra was inhibited. Reduction in plant height conforms to the observation of Tong and Liange, (2005) and is in agreement with the work of Dursun *et al*. (2002). The reduction in plant growth might have been caused by the injuries, reduced photosynthesis and other physiological disorders. In a similar study, Waldron (1978) stated that the pH level is responsible for reduction in plant growth. The observed stunted growth for plants treated with SAR pH 3.5 and 2.7 was similar to an earlier study by Singh and Agrawal (2001).

Leaf number: Figure 2 (A & B), shows the effect of SAR exposure at different pH levels and frequency of SAR application on leaf number of *A. esculentus*, respectively. The results indicated that under the stress of SAR and frequency of SAR application, number of leaves decreased with increased in acid rain, from 3 to 7 WAS. Considering the effect of SAR (Fig. 2A), the mean highest leaf number was determined at control (6.78) and while, the mean least leaf number of 3.63 was recorded in coke treatment. Considering the effect of frequency of SAR application (Fig. 2B), the mean highest leaf number (5.55) was determined at a weekly application of SAR while, the mean least number of leaf (2.75) was observed at an application of thrice a week. With regards to the interaction effects (Table 1), higher leaf numbers were observed in the control pots but, decrease in number with increase in plant growth from 3 to 7 WAS. This is in agreement with the work of Dursun *et al*., (2002) and Tong and Liange, (2005) who confirmed that the higher the acidity, the more the number of leaves are inhibited.

Leaf area: Figure 3 (A & B), shows the effect of SAR exposure at different pH levels and frequency of SAR application on leaf area (LA) of *A. esculentus*, respectively. The results indicate that under the exposure of SAR and frequency of SAR application, the LA decreased with increased in acid rain, from 3 to 7 WAS. Considering the effect of SAR levels on the LA (Fig. 2A), the mean widest LA was determined at control (607.33 mm) and while, the mean least leaf number of 252.33 mm was recorded in coke treatment. Considering the effect of frequency of SAR application (Fig. 2B), the mean highest LA (436.67mm) was determined at a weekly application of SAR while, the mean least number of leaf (352.43 mm) was observed at an application of thrice a week. With regards to the interaction effects (Table 1), wider LA were observed in the control treatments but, decrease in

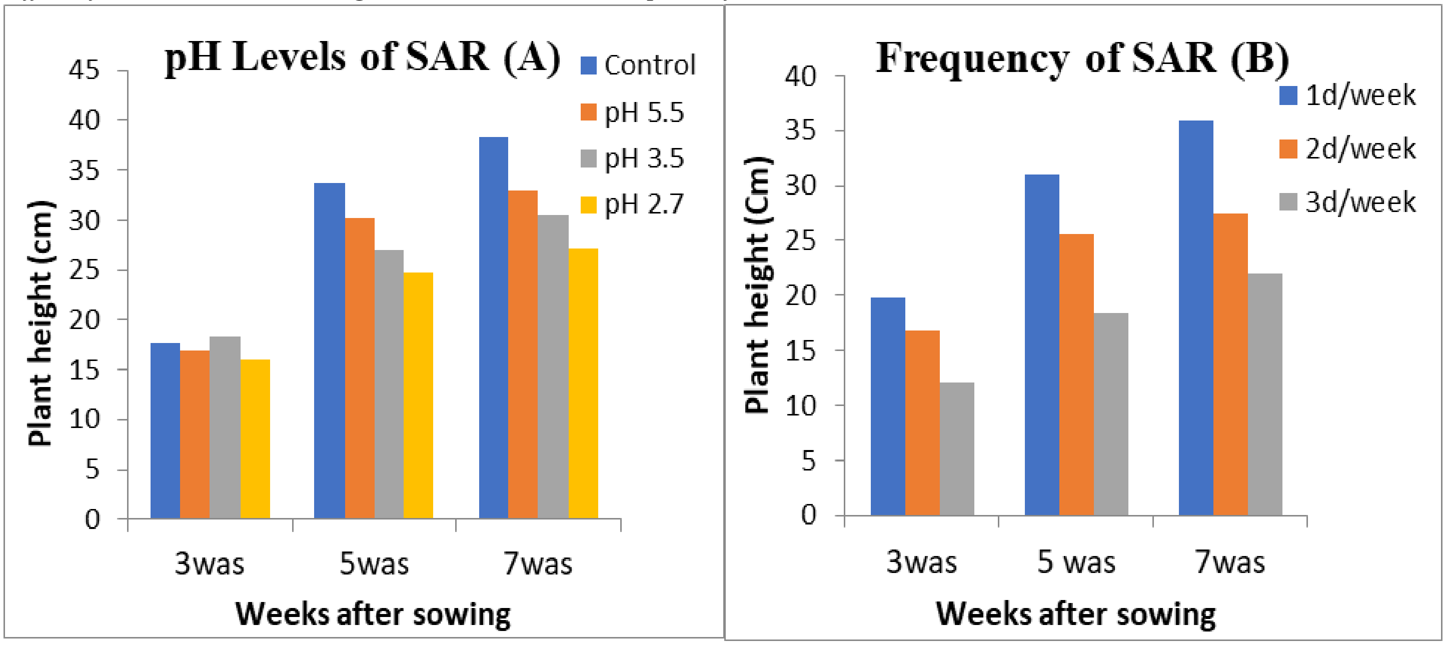

Figure 1: Effects of pH levels of SAR (A) and frequency of SAR (B) on plant height of okra @ 3, 5 and 7 weeks after sowing (WAS).

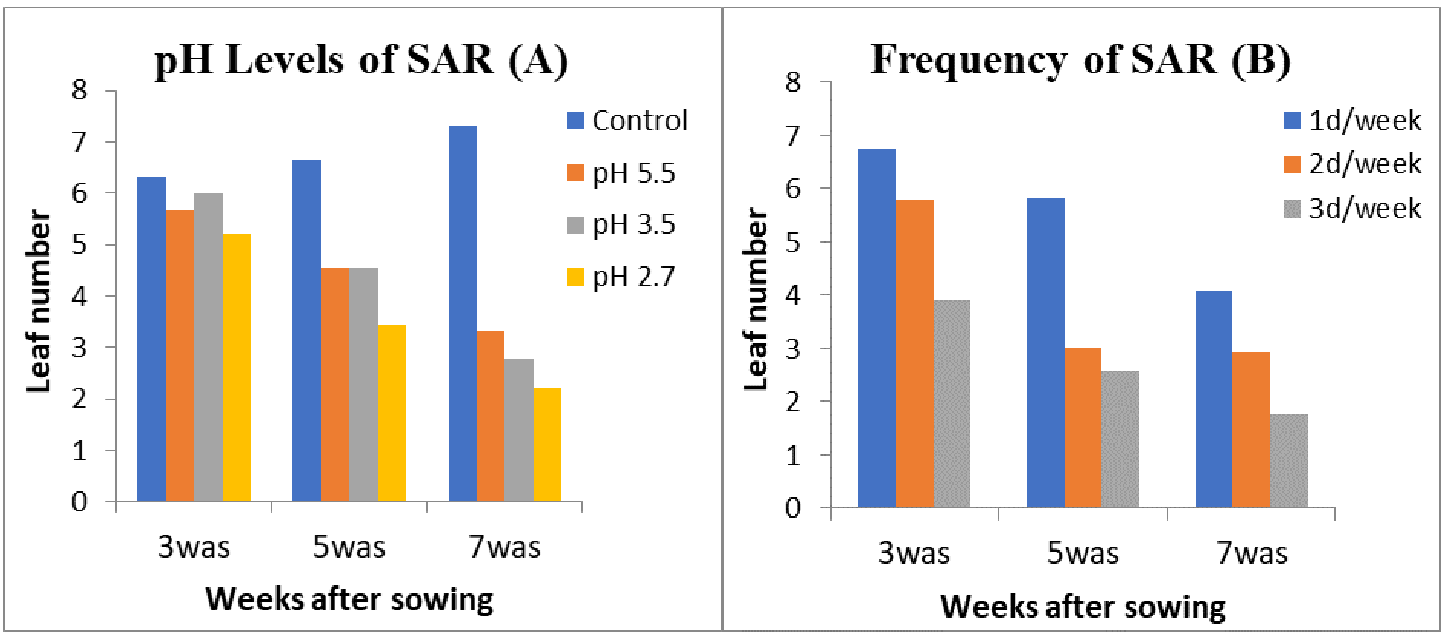

Figure 2: Effects of pH levels of SAR (A) and frequency of SAR (B) on plant leaf number of okra @ 3, 5 and 7 weeks after sowing (WAS).

leaf size with increase in plant growth from 3 to 7 WAS. The reduction in leaf size conforms to observation of (Tong and Liange, 2005).

The sequential reduction of leaf size of okra was proportional to the decrease in the concentration of pH value as well as, the increased in the frequency of SAR application to three times a week. This is in agreement with the work of Dursun *et al*., (2002) and Tong and Liange, (2005), who confirmed that the higher the acidity, the more the LA was inhibition. The adverse effects of simulated acid rain on plant growth parameters on several crops were equally reported by Banwart *et al.* (1988), Evans *et al.* (1997) and Halman *et al.* (2008) respectively. A more recent report by Madiha *et al.* (2014) revealed that simulated AR also caused reduction in plant growth and yield of field corn, green pepper and tomato.

The above results indicate that under the stress of simulated acid rain, the shoot height and number of leaves and size of leaf 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*, (2002). Size of the leaves also decrease due to thinner mesophyll cells. Reduction in leaf size conforms to observation of Liange (2005). Other morphological changes observed in this experiment (necrosis, chlorosis and deformation of leaf and terminal bud) is in accordance with the study of Dursun *et al.*, (2002) and Odiyi and Bamidele, (2013). It can be deduced from Table 1, that the control had the highest shoot height, number of leaves and size of leaf before and after exposure com-

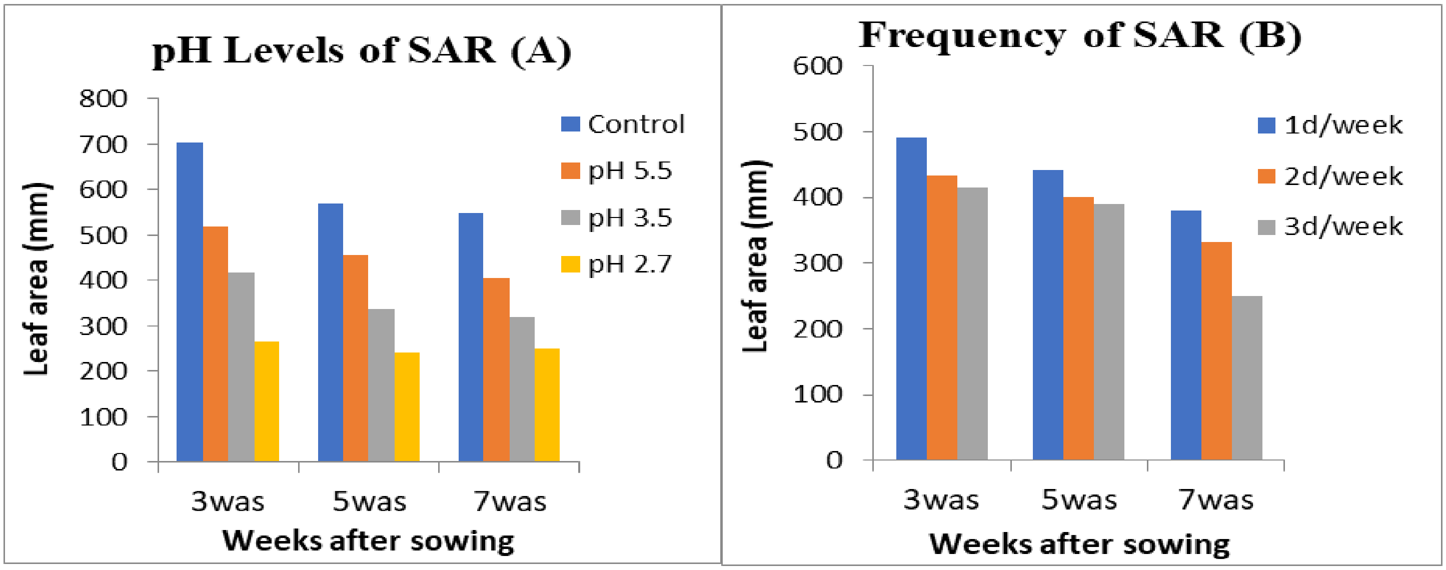

Figure 1: Effects of pH levels of SAR (A) and frequency of SAR (B) on plant height of okra @ 3, 5 and 7 weeks after sowing (WAS).

Table 1: Interaction effects of SAR and frequency of foliar spray on growth performance of Okra

Treatments	Plant height (cm)			Leaf number			Leaf area (cm^2)		
	3was	5was	7was	3was	5was	7was	3was	5was	7was
Control	21.33	34.33	38.33	7.34	6.17	5.53	703.0	571.00	548.0
Once weekly SAR application									
pH 5.5	18.67	33.67	37.67	6.33	5.40	4.03	626.0	549.0	503.0
pH 3.5	17.54	29.33	31.33	5.70	4.33	3.00	440.0	336.0	309.0
pH 2.7 (Coke)	16.00	24.33	27.33	4.70	3.53	2.37	328.0	282.0	277.0
Mean	17.43	29.11	32.11	5.58	4.42	3.13	465.0	389.0	363.0
Twice weekly SAR application									
pH 5.5	18.21	32.00	35.00	6.20	5.00	3.73	545.0	485.0	438.0
pH 3.5	17.00	27.33	31.00	5.40	4.30	2.87	389.0	334.0	289.0
pH 2.7 (Coke)	15.33	24.00	27.00	4.27	3.33	2.33	287.0	254.0	255.0
Mean	16.85	27.78	31.00	5.29	4.21	2.98	407.0	358.0	327.0
Thrice weekly SAR application									
pH 5.5	17.87	30.67	33.33	6.10	4.67	3.43	500.0	392.0	355.0
pH 3.5	16.67	25.33	27.93	5.30	4.13	2.67	310.0	306.0	273.0
pH 2.7 (Coke)	12.33	20.33	26.67	3.67	2.67	1.47	177.0	164.0	224.0
Mean	15.62	25.44	29.31	5.02	3.82	2.52	329.0	287.0	284.0
G. Mean	17.22	29.64	32.47	5.81	4.81	3.92	476.0	401.0	381.0
LSD (0.05)	5.11	6.04	7.76	1.90	1.57	1.15	293.1	227.6	188.4
CV (%)	17.50	12.00	14.10	19.30	19.30	17.40	36.40	33.50	29.20
F-test	N. S	N. S	N. S	N. S	N. S	N. S	N. S	N. S	N. S

Significance level of the F-test for interaction effects with NS denoting not significant, for two-sided t-test.

pared to pH 3.5 and 2.7 which had the least morphological parameters.

3.2 Effects of SAR and frequency of SAR on micronutrients (Cu, Fe, Mn and Zn) content in okra

The micronutrients content of *A. esculentus* were significantly ($P \leq 0.001$) affected by simulated acid rain (SAR) exposure at different pH levels (Table 2), frequency of SAR application (Table 2) and their interaction (Table 3), respectively. The results indicated that under the stress of simulated acid rain, micronutrients content in *A. esculentus* reduced with the declining pH value of acid rain and frequency of SAR application. Statistically, there was significant difference between SAR treatments and control plants.

Copper (Cu): There was a significant reduction in Cu content of the test plants as the concentrations of the SAR pH reduced in value. Considering the main effect of SAR (Table 2), there was significant increase in Cu content from pH 5.5 (4.11 mgkg^{-1}) to pH 2.7 (7.01 mgkg^{-1}) relative to control (3.27 mgkg^{-1}), with a mean Cu content of 4.98 mgkg^{-1}. Considering the effect of frequency of SAR application (Table 2), there was significant increase in Cu content from 1d/week (6.58 mgkg^{-1}) to 3d/week (11.63 mgkg^{-1}) with a mean Cu content of 9.08 mgkg^{-1}. With regards to the interaction effects (Table 3), higher Cu content (21.22 mgkg^{-1}) was determined in Coke (pH 2.7) treatment applied at 2d/week while, the lowest Cu content (14.42 mgkg^{-1}) was determined in pH 5.5 applied at 1d/weekly application of SAR relative to control which were statistically not significant. The result is at par with previous studies reported by Arti *et al.*, 2010, Meng *et al.*, 2011, Eguagie, (2015).

Iron (Fe): Considering the main effect of SAR (Table 2) there was a significant increase in Fe content from 51.77 mgkg^{-1} (pH 5.5) to 93.42 mgkg^{-1} (pH 2.7), relative to control (34.31 mgkg^{-1}) with a mean Fe content of 64.86 mgkg^{-1}. Considering the effect of frequency of SAR application (Table 2), there was significant increase in Fe content from 49.94 mgkg^{-1} (1d/week) to 88.99 mgkg^{-1} (3d/week) with a mean Fe content of 69.85 mgkg^{-1}. With regards to the interaction effects (Table 3), higher Fe content (206.03 mgkg^{-1}) was determined in Coke (pH 2.7) solution applied at 3d/week while, the lowest Fe content of 63.34 mgkg^{-1} was determined in SAR (pH 5.5) applied at 1d/week relative to the control. The result is at par with previous studies reported by Arti *et al.*, 2010, Meng *et al.*, 2011, Eguagie, (2015).

Manganese (Mn): Considering the main effect of SAR (Table 2), the mean highest Mn content (85.63 mg kg^{-1}) was determined under Coke (pH 2.7) while, mean lowest Mn value (49.43 mgkg^{-1}) in okra was obtained under pH 5.5 treatment relative to control (22.91 mgkg^{-1}) with an average Mn content of 55.11 mgkg^{-1}. Considering the effect of frequency of SAR application (Table 2), there was significant increase in Mn content from 1d/week (37.91 mgkg^{-1}) to 3d/week (91.27 mgkg^{-1}) with a mean Mn content of 55.40 mgkg^{-1}. With regards to the interaction effects (Table 4.5), higher Mn content of 395.51 mgkg^{-1} was determined in Coke (pH 2.7) treatment applied at 3d/week while, the lowest Mn content of 123.66 mgkg^{-1} was determined in pH 5.5 applied at 1d/week relative to the control. The result is at par with previous studies reported by Wang *et al.*, (2000), Khan and Shikha (2004), Khan and Deopura (2005), Meng *et al.*, 2011, Imran *et al.*, (2014).

Zinc (Zn): Considering the main effect of SAR (Table 2), the mean highest Zn content (68.84 mg kg^{-1}) was determined under Coke (pH 2.7) solution while, mean least Zn value (32.16 mgkg^{-1}) in okra was obtained under pH 5.5 treatment relative to the control (15.73 mgkg^{-1}) with a mean value of 41.98 mgkg^{-1}. Considering the effect of frequency of SAR application (Table 2), there was significant increase in Zn content from 1d/week (27.02 mg kg^{-1}) to 3d/week (63.77 mgkg^{-1}) with a mean Mn content of 45.08 mg kg^{-1}. With regards to the interaction effects (Table 4.5), higher Zn content (142.02 mgkg^{-1}) was determined in Coke (pH 2.7) treatment applied at 2d/week while, the lowest Zn content (34.84 mg kg^{-1}) was determined in pH 5.5 applied at 1d/weekly application of SAR. The result is at agreement with previous studies reported by Meng *et al.*, (2011) and Eguagie *et al,* (2016).

4.0. Conclusion

This study examined the impact of simulated acid rain and frequency of SAR on growth and micronutrients content of okra (*Abelmoschus esculentus*) in an ultisol at Umudike.

It is evident from this study that under the stress of simulated acid rain (SAR) exposure at pH value below 5.5, had negative effect on the growth component (shoot height, number of leaves and LA) which decreased with the declining pH value of acid rain and this markedly suppressed fruit formation of *A. esculentus* due to the reduction of photosynthesis as a result of chlorosis, necrosis and leaf abscission coupled with dehydration of the plants.

Table 2: Effects of SAR and frequency of SAR application Cu, Fe, Mn and Zn content in okra

Treatments	Micronutrients (mgkg^{-1}) in okra leaf			
	Cu	**Fe**	**Mn**	**Zn**
pH levels of SAR				
Control	3.27	34.31	22.91	15.73
pH 5.5	4.11	51.77	49.43	32.16
pH 3.5	5.54	79.95	62.45	51.17
pH 2.7 (coke)	7.11	93.42	85.63	68.84
Mean	5.01	64.86	55.11	41.98
LSD (0.05)	1.97	42.44	55.99	6.44
CV (%)	22.21	25.60	18.42	15.81
F-test	***	***	***	***
Frequency SAR application				
1d/weekly	6.58	49.94	37.91	27.02
2d/weekly	9.04	70.63	57.03	44.45
3d/weekly	11.63	88.99	91.27	63.77
Mean	9.08	69.85	55.40	45.08
LSD (0.05)	1.71	36.76	48.49	5.58
CV (%)	22.2	25.60	18.44	15.82
F-test	***	***	***	***

Significance level of the F-test for treatment effects with *** denoting P < 0.001, for two-sided t-test.

Table 3: Interaction effects of SAR and frequency of SAR on Micronutrients content of Okra

Treatments	Micronutrients (mgkg^{-1})			
	Cu	Fe	Mn	Zn
Control	12.50	43.43	106.57	29.37
1d/weekly				
pH 5.5	14.42	63.43	124.66	34.84
pH 3.5	15.50	91.35	221.34	44.03
pH 2.7 (coke)	18.63	115.01	312.07	67.02
Mean	16.18	89.93	219.36	48.63
2d/weekly				
pH 5.5	16.30	97.35	149.72	42.61
pH 3.5	19.50	108.06	267.32	57.22
pH 2.7 (coke)	21.22	125.47	345.39	89.55
Mean	19.01	110.29	254.14	63.13
3d/weekly				
pH 5.5	19.83	114.76	171.16	69.27
pH 3.5	15.17	172.22	288.56	66.88
pH 2.7 (coke)	10.33	206.03	395.51	142.02
Mean	15.11	164.33	285.08	92.72
G. Mean	13.11	121.52	271.51	90.75
LSD (0.05)	3.42	73.52	96.97	11.16
CV (%)	22.20	25.60	18.43	15.82
F-test	N. S	***	**	**

Significance level of the F-test for interaction effects with NS, *, ** and *** denoting not significant, $P < 0.05$, 0.01 and 0.001, respectively, for two-sided t-test.

Except for the accumulation of micronutrients, which increased with declining pH value of acid rain and frequency of application, all the plant growth parameters studied such as plant height, number of leaves and leaf area of *A. esculentus* decreased significantly with the declining pH value of acid rain and frequency of application with respect to the control treatment.

Coke solution (pH 2.7 levels) and three (3) days per weekly application of SAR gave the highest reduction in plant growth parameter in Okra but, had higher increased in micronutrients, respectively.

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