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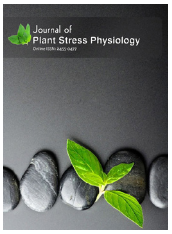

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Growth and total photosynthetic pigment responses of five accessions of *Zea mays* L. grown under waterlogging stress

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ABSTRACT

The effect of waterlogging on the growth of five accessions of *Zea mays* was investigated. The growth parameters, evaluated from 2 WAP (Weeks after planting) included: leaf area, number of nodes, total photosynthetic pigment (TPP) as well as plant height. Results revealed that TZM-4 (7.00±0.296 cm) showed a higher growth under waterlogging stress as observed in shoot length, whilst TZM-5 recorded the lowest growth with (4.83±0.17 cm). Results for the estimation of the total photosynthetic pigment; TZM-4 was observed to have retained a high value (28.23±8.63 mg/kg), while TZM-1 showed the lowest value (15.33±3.23 mg/kg) after 4WAP. For the number of nodes, TZM-1 recorded a high value (4.67±4.67), while TZM-5 had the lowest value (2.33±1.20). By observation, TZM-5 showed a better overall waterlogging tolerance which could be attributed to the development of adventitious roots which aided aeration. Hence, waterlogging stress had negative effects on the growth and TPP of *Z. mays*. However, TZM-5 showed promising advantage under waterlogging condition while TZM-3 showed poor tolerance in growth rate which makes it a non-favorable choice for planting in waterlogged soil. Thus, this research provides a promising insight for breeders and plant scientists to capitalize on for the breeding of this very important economic crop for sustainable agriculture and food security in a world threatened by climate change.

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KEYWORDS: Adventitious roots system, Photosynthetic pigment, Waterlogging, *Zea mays*

INTRODUCTION

Waterlogging remains a significant constraint to maize production across the globe in areas with high rainfall and/or poor drainage. Improving the tolerance of plants to waterlogging is the most economical way of tackling the problem. However, under severe waterlogging, combined agronomic, engineering and genetic solutions will be more effective (Manik *et al.*, 2019). Frequent extreme precipitations lead to waterlogging stress and the duration changes with rainfall intensity, drainage and soil structure (Malik *et al.*, 2002). Waterlogging may affect 12% of global cultivation areas, possibly causing up to 20% yield loss (Shabala, 2011). The performance of plants in response to waterlogging depends closely on the plant growth stage, the depth of water level, and the duration of waterlogging events (Davies *et al.*, 2000; Malik *et al.*, 2001, 2002).

Waterlogging lowers the oxygen level in the root zone, which reduce plant growth. Waterlogging has direct and indirect effect on plant growth and yield. It causes the air within the soil to move out into the atmosphere, replacing it with more water. The inadequate supply of oxygen retards or ceases the growth of a plant as the accumulating carbon dioxide hampers the growth of the plants root.

On the basis of the above, this research was carried out to assess the effect of waterlogging stress on the growth of different accessions of *Z. mays* (maize) and also to investigate the water tolerance level of *Z. mays*.

MATERIALS AND METHOD

Source of Plant Materials

Five (5) accession *Zea mays* were collected from the International Institute for Tropical Agriculture (IITA), Ibadan Oyo State Nigeria. The experiment was carried out at the Department of Botany Greenhouse, Akwa Ibom State University Ikot Akpaden, Akwa Ibom State, Nigeria.

Planting Procedures

Five (5) seeds were sown at 3 cm depth in planting bucket (10 liters) filled with a well-sterilized loamy soil, three replicate were made for each accession, well labeled and laid out in a complete block design (CBD).

Physicochemical Properties of the Soil

Composite surface soil samples of 0-15 cm depth were randomly taken. The samples were carefully labeled and packaged in polythene bags for laboratory analyses. The soil samples were air dried ground and passed through a 2 mm sieve to remove materials greater than 2 mm in diameter. The sieved samples were subjected to particle size analysis which was determined by the Bouyoucos hydrometer method as outlined by Jackson and Drew (1984), using calgon (sodium hexametaphosphate) as a dispersing agent.

Soil pH was determined in a 1:2.5 soil/water ratio in suspension using a glass electrode pH meter. Organic carbon was determined by the Walkley and Black wet oxidation method. The values of organic carbon were multiplied by a Vanbameller factor of 1.724 to obtain values for organic matter. Electrical conductivity (EC) was determined using conductivity bridge by dipping the electrode into the soil- water suspension (Hanna, 1964).

Available phosphorus was extracted by the Bray 1 extraction method (Bray & Kurtz, 1945), and the content of P was determined calorimetrically. Determination of exchangeable bases was by neutral ammonium acetate extraction and read with an Atomic Absorption Spectrophotometer (AAS).

Exchangeable acidity was determined by the 1 N KCl extraction method (McLean, 1965) and titrated with 1 M sodium hydroxide (NaOH) using phenolphthalein as an indicator. The effective cation exchange capacity (ECEC) was obtained as the summation of the total exchangeable bases and exchangeable acidity.

Determination of Leaf Area

The leaf area (LA) was determined some days after the sprouting measurement was obtained using the measuring rule, the Area (A) of the Leaf was determined by tracing the outline, and the activities of the leave on the measuring tape. The area covered by the outline was then calculated. The correlation factor (K) was determined by dividing the area (A) by the product of length x breadth of the leaf, therefore, the leaf area for each plant was determined using the formula:

$$A = L \times P$$

Where: A = the traced area
L = Leaf length
B = Leaf width.

Determination of Shoot Length

The shoot length was obtained by measuring the height of the plant using a tape.

Number of Nodes

The number of nodes was obtained by counting the total number of leaves present in each stand.

Determination of Root Length

The root length was determined using a ruler to measure the root of the plant after being uprooted from the soil.

Determination of Total Fresh Weight

The total fresh weight was determined by oven drying at 70 °C to a steady weight.

Determination of Total Photosynthetic Pigment

The atLeaf chlorophyll meter was used for non-destructive estimation of the total photosynthetic (TPP) contents of *Z. mays*. The atLeaf chlorophyll meter was pinned on the leaf surface and the reading was taken in triplicate.

Determination of Shoot Fresh Weight

The shoot fresh weight of the plant (*Z. mays*) was determined by weighing the plant on a weighing balance to determine the shoot fresh weight.

Determination of Shoot/Root Dry Weight

The shoot and root of the plant (*Z. mays*) were oven dried and later weighed using a weighing balance to determine the dry weight.

RESULTS AND DISCUSSION

Physicochemical Properties of Composite Surface Soil Samples

The physicochemical properties of composite surface soil sample are shown in (Table 1). The soil texture was predominantly loamy sand soil, sand in loamy soil was 830 g/kg, while slit was 70 g/kg and clay in loamy soil was 100 g/kg. Considering the three particles of the soil, sand has the highest distribution followed by clay and slit. The pH value of the soil was 5.6 which indicate slightly acidic. This may be due to excessive leaching because of the high amount of rainfall in the area. Then organic matter (DM) of the surface was 4.32% that is the high level of organic matter may be due to luxuriant vegetation mainly grasses and shrubs. Exchangeable Ca, Mg, Na and K were 0.66%, 0.30 Cmol/kg, 0.11 Cmol/kg and 0.40 Cmol/kg respectively.

Table 1: Physicochemical Properties of the Experimental Soil

S/N	Parameter	Garden Soil
1	pH	5.6
2	Sand (g/kg)	830
3	Silt (g/kg)	70
4	Clay	100
5	Texture	Loamy Soil
6	Organic matter	4.32
7	Total nitrogen	1.16
8	Ex. Ca (mol/kg)	0.66
9	Ex. mg (cmol/kg)	0.30
10	Ex. mg (cmol/kg)	0.11
11	Ex. k (cmol/kg)	0.40
12	ECEC (cmol/kg)	2.50
13	Base saturation (%)	60
14	P (ma.kg)	13.10
15	TEA	1.03
16	EC	0.67
18	BD (g/cm)	1.47

pH - Hydrogen ion Concentration, P - Phosphorous, Ex - Exchange, Kg - Kilogram, ECEC- Effective Cation Exchange Capacity, EC - Electrical Conductivity, TEA - Total Exchange Acidity, BD - Bulk Density and OM - Organic Matter

The exchangeable Ca was moderate then exchangeable mg content in the soil was recorded as low below the critical value of 0.5 exchangeable Na was very low and the exchangeable content of K was moderate which was lower than the critical of 0.2 Cmol/Kg. Calcium and potassium were the dominant exchangeable bases in decreasing amounts in the order Ca K Mg Na. The effective cation exchangeable capacity (ECEC) ranged from 2.50 Cmol/Kg. The percentage base saturation (BS) was 60%. The high value of BS could be due to the high level of calcium and potassium which indicates the availability of some basic cation of a fertile soil.

Phosphorus (P) content was 13.10 mg/kg indicating the low level availability of P in the soil. This may be due to the acidic nature of the soil. The electrical conductivity (EC) of the soil was 0.067. EC is the measure of total cation and anions in soil solution. Total nitrogen (TN) content was 0.16%. The low level of total N could be attributed to the leaching of nitrate due to excessive rainfall (Table 1).

Effect of Waterlogging on the Total Photosynthetic Pigment of Different Accession of *Zea Mays*

The effect of waterlogging on the growth of five accessions of *Z. mays;* the parameters such as leaf area, number of nodes, shoot length and total photosynthetic pigment were significantly decreased (p=0.05) in growth on the treatment when compared to the control.

At week four after uprooting, the following characters were considered and evaluated the total fresh weight, leaf dry weight, root length, root fresh weight, and shoot fresh weight. Tzm-2 showed the highest waterlogging tolerance as observed in plant height at two weeks (Table 2) Tzm-2 (C=25.00±6.46) and Tzm-4 recorded the lowest value for waterlogging tolerance in plant height with (C=4.27±0.67) respectively. For leaf area at four weeks, Tzm-1 recorded (T=18.13±5.54) and Tzm-5 recorded the lowest value for waterlogging in leaf area with (T=2.53±1.59) (Table 5). The number of nodes at three weeks recorded Tzm-3 (C=12.75±2.65) and Tzm-5 (C=3.00±3.00) recorded the lowest value for waterlogging tolerance in the number of nodes. For total photosynthetic pigment Tzm-5 (25.00±6.46) had the highest value while Tzm-1 (15.33±3.23) recorded the lowest.

Table 2: Effect of waterlogging on the total photosynthetic pigment of different accession of *Zea mays*

Accession	Treatment (mg/kg)	2WAP (mg/kg)	4WAP (mg/kg)
TZM$_1$	T	29.70±9.16	15.33±3.23
	C	40.10±2.78	29.33±2.54
TZM$_2$	T	40.10±2.78	15.73±9.79
	C	39.03±2.08	30.70±1.03
TZM$_3$	T	40.43±4.79	15.47±8.23
	C	45.97±4.81	40±5.2634
TZM$_4$	T	40.70±1.54	28.23±8.63
	C	41.60±2.90	28.9±5.09
TZM$_5$	T	28.07±5.01	20.43±5.58
	C	40.30±1.17	25.00±6.46

Table 3: Effects of Waterlogging on the Plant Height of different Accession of Zea mays

Accession	Treatment (cm)	2WAP	3WAP	4WAP
TZM$_1$	T	5.27±0.47	6.37±0.88	5.63±0.32
	C	5.27±0.16	4.77±0.27	4.97±0.29
TZM$_2$	T	6.50±0.30	5.07±1.36	4.43±0.92
	C	5.00±6.46	4.40±0.31	4.67±0.33
TZM$_3$	T	6.43±0.67	6.57±0.63	7.33±0.33
	C	5.93±0.64	6.63±0.73	6.83±0.44
TZM$_4$	T	4.67±0.37	7.00±0.29	70.00±0.29
	C	4.27±0.67	5.03±0.27	6.17±0.88
TZM$_5$	T	5.23±0.03	4.97±0.84	4.90±0.66
	C	4.60±0.35	5.20±0.10	4.83±0.17

Table 4: Effects of waterlogging on the number of nodes of different accession of Zea mays

Accession	Treatment	2WAP	3WAP	4WAP
TZM$_1$	T	3.33±2.02	3.00±1.73	3.33±2.02
	C	3.66±3.66	3.30±33.33	3.66±3.66
TZM$_2$	T	3.33±2.02	5.00±2.64	3.33±2.02
	C	4.67±4.47	4.00±4.00	3.33±3.33
TZM$_3$	T	3.66±3.75	3.66±3.75	3.33±2.02
	C	8.00±4.36	12.75±2.65	14.67±4.67
TZM$_4$	T	3.66±2.33	8.00±4.36	3.66±2.33
	C	3.33±2.02	3.66±3.66	3.66±3.66
TZM$_5$	T	4.67±4.47	5.00±2.67	2.33±1.20
	C	3.33±2.42	3.00±3.00	3.33±3.33

Table 5: Effect of waterlogging on the leaf area of different accession of *Zea mays*

Accession	Treatment	2WAP (cm^2)	3WAP (cm^2)	4WAP (cm^2)
TZM$_1$	T	6.34±086	14.48±6.16	18.13±5.54
	C	10.60±3.39	86.45±67.03	13.68±4.77
TZM$_2$	T	11.83±3.26	35.85±22.19	6.75±0.48
	C	4.03±0.48	10.728±4.07	12.42±5.87
TZM$_3$	T	6.87±1.67	0.13±0.98	8.29±0.97
	C	6.37±0.49	0.75±0.49	5.36±1.16
TZM$_4$	T	5.82±1.09	8.03±2.23	8.73±2.47
	C	5.01±0.23	4.77±0.23	8.04±2.03
TZM$_5$	T	5.46±0.99	0.12±0.72	2.53±1.59
	C	4.03±1.27	28.21±20.06	4.71±0.50

Table 6: After parameter harvest

Accession	Treatment	RL (cm^2)	Tfw (g)	Sfw (g)	Rfw (g)	Tdw (g)	Rdw (g)	Sdw (g)
TZM_1	T	32.17±4.41	6.67	2.41	5.11	1.42	0.63	0.48
	C	27.50±2.50	5.62	2.46	2.82	1.31	0.50	0.23
TZM_2	T	28.50±1.50	6.67	2.21	3.48	1.32	0.81	0.60
	C	18.60±2.53	5.62	2.03	0.07	1.08	0.42	0.26
TZM_3	T	25.50±1.53	7.52	2.41	1.70	1.55	0.63	0.77
	C	21.60±4.36	5.71	2.77	3.33	1.27	0.42	0.74
TZM_4	T	27.17±1.20	8.04	2.56	3.11	1.32	0.81	0.53
	C	10.57±0.54	5.05	2.20	0.89	0.96	0.48	0.45
TZM_5	T	21.17±4.70	2.33	1.17	0.01	1.24	0.81	0.61
	C	15.57±4.81	2.72	0.49	0.41	1.12	0.46	0.31

RL - Root Length, Tdw - Total Dry Weight, Tfw - Total Fresh Weight, Rdw - Root Dry Weight, Sfw - Shoot Fresh Weight, Sdw - Shoot Dry Weight and Rfw - Root Fresh Weight

The effect of waterlogging stress on plant height and number of nodes of Z. *mays* is given on Tables 3 and 4 respectively. The effect of waterlogging stress on after harvest parameters and biomass yield of Z. *mays* is given on Table 6.

DISCUSSION

Results of this study showed that waterlogging significantly ($p=0.05$) decreased the growth of Z. *mays*. However, TZM-5 showed a better tolerance to waterlogging than others. This was a result of the development of an adventitious root system by this plant which aid in the exchange of gases and absorption of water nutrients for plant growth. The root developed outside the soil at the base of the stem. This result agrees with Visser and Voesenek (2005), who reported that the formation of an adventitious roots system (ARS) is a typical adaptive change in morphology.

During extended waterlogging, ARS develop in the internodes on the hypocotyl or at the base of the stem, where they promote the exchange of gases and absorption of water and nutrients. To a certain extent, AR formation can replace the primary roots that die because of hypoxia stress, maintaining metabolic cycles and enabling normal growth and development. The newly formed ARS contain more aerenchyma than the primary roots, which augment both O_2 uptake and diffusion ability. Aerenchyma not only can transport O_2 from non-waterlogged tissue to the root system but also discharge CO_2 and toxic volatile substances from waterlogged tissue. By observations, the results showed that TZM-4 had a higher tolerance for waterlogging. This is because the seed of Z. *mays* tend to flourish more in terms of their morphological features such as leaf area, petiole length, shoot length and number of nodes compared to other accessions.

Results further revealed that TZM-4 had a higher waterlogging tolerance when compared to other accessions. TZM-1 had a lower tolerance for waterlogging because the seed did not show much increase in its morphological features when compared to accession TZM-4. Mabhaudhi and Modi (2011) showed that seed germination and area of the leaf (LAI) of Z. *mays* are reduced by water stress.

When plants suffer from water stress, the stomata close maximizing the plants water consumption and reducing CO_2 emissions. Not only the seeds are affected by water stress, but also the leaves and roots, leading to a decrease in stomata conductance and photosynthetic rate (Sinefu, 2011). Thus, waterlogging had a negative effect on the growth of Z. *mays*.

CONCLUSION

From the result obtained from this study, it could be concluded that waterlogging significantly ($p=0.5$) decreased the growth of Z. *mays*. However, TZM-5 showed better tolerance to waterlogging than the others. The study therefore recommends that in areas with waterlogging soil condition, maize should not be cultivated as it has poor and relatively low tolerance towards withstanding the impact of water stress. Moreso, the crop requires moderate water condition in order for it to survive and yield growth.

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