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Performance of Pearl Millet (*Pennisetum glaucum* L.) Under Water Stress At Various Stages Of Growth And Development in Sudan savanna, Nigeria

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ABSTRACT

Pearl millet is an important crop in the Arid and Semi-arid areas of the world. The crop is tolerant to water stress and low soil fertility. However, timing of water supply to pearl millet is critical to its productivity. Therefore, this research investigated the effect of water stress (deficit) at various stages of pearl millet growth to determine the critical periods of development. A greenhouse experiment was carried out at Dutsinma (12.455° N and 7.498° E; elevation: 605 m) in Katsina State, using six treatments (T1, T2, T3, T4, T5 & T6) involving water stress during leaf stage (T1), panicle initiation stage (T2), boot stage (T3), milk stage (T4), dough stage (T5) and control treatment (T6). The control treatment did not receive any water stress. Generally, results indicated that compared to control treatment, water stress during the boot and dough stages of development significantly improved leaf area and plant height while water stress during the milk stage significantly increased the dry matter yield (DMY) of pearl millet. The results suggest that fresh matter yield of pearl millet can be improved by water stress during boot or dough stages of growth while dry matter yield can be increased by water stress at milk stage of development.

Keywords: water supply, Pearl millet, growth stages

INTRODUCTION

Pearl millet is among the four most important crops (rice, maize, sorghum and millet) in the arid and semi-arid tropics of the world (FAO, 2017). It is staple food to more than 100 million people living in low income countries (Earl, 2018). Pearl millet is nutritious and contains high amount of protein (9-16%), Calcium (37 mg), Iron (17 mg), Phosphorus (340 mg) and traces of Copper, Zinc, Manganese, Chromium, Iodine, Cobalt and Molybdenum (National Academy of Sciences, 2018). Moreover, the crop is climate resilient and is easily grown in the dry Northern parts of Nigeria due to its ability to tolerate drought, flood, high temperature and low soil fertility (Santosh et al., 2016). Water stress is due to either excess water or water-deficit conditions. Mostly, the water-deficit stress (drought) is more common and it affects the growth and development of crop plants (Oliveira and Farias, 2014). Water stress can affect the quality of crops both negatively and positively (Stagneri et. al, 2016). Plants exposed to water deficit in the form of drought become stressful in just few days which can lead to losses in potential crop yield by up to 88% (Taiz and Zeiger, 2002). The productivity of plants under drought depends on the total amount of available water and the water use efficiency of the crop plant. The plants that resist drought better are those with higher water-use efficiency or plants that have the ability to acquire more water.

Water deficit (drought) is a situation whereby the water content of cell or tissue is below the highest water content exhibited at the most hydrated state. Water stress can limit leaf expansion and consequently reduce photosynthesis or crop yield. Water stress stimulates leaf abscission (fall off) to reduce the number of leaves or total leaf area of a plant. Moreover, water deficit enhances root extension in to deeper soil zones that are moist. Generally, shoot continue to grow until water uptake by roots becomes limiting, while roots continue to grow until their demand for photosynthates from shoot equals to the supply (Taiz and Zeiger, 2002). Water deficit is known to frequently limit crop yield (Tisdale et al., 2003). For pearl millet that is highly drought tolerant, water stress can still lead to lower yields (Jennings et. al, 2021). Moreover, water is regarded as the most limiting factor to improve pearl millet yield. Timing of water supply is more important than total water supply in pearl millet production (Khairwal et. al, 2007). Research on pearl millet is low due to scarce economic and technological support (Macauley and Ramadjita, 2015). Therefore, more research on pearl millet needs to be conducted so as to improve its nutritional quality and yield. Hence, the objective of this study was to determine the yield of pearl millet as influenced by drought regimes at various stages of growth to indicate periods that are critical to the production of the crop which is widely grown and consumed in the study area.

MATERIALS AND METHODS

Study Area

The study was conducted in the year 2024 at the greenhouse facility of Isa Kaita College of Education Dutsinma (12.455° N and 7.498° E; elevation: 605 m) in Katsina State. The area lies within the Sudan Savanna of Nigeria. The climate is that of 'tropical wet and dry' koppen system denoted as 'Aw'. Insolation is high due to low cloud cover. Average daily sunshine is about 9 hours per day. The long dry season is between November to May (relative humidity is than 40%), while the short wet season is between June and October (Okonkwo, 2010). Annual rainfall is 700 mm (long term average data), while average temperature is 25 ± 7^{o} C throughout the year (Shehu et al., 2015).

Soil Sampling And Analyses

Composite soil sample was collected in April, 2024. Soil was sampled at a depth of 0-20cm (zig-zag pattern). Equal amounts of soil samples were mixed to form one composite sample. Composite soil sample was air-dried and crushed to pass through a 2mm sieve. 3 sub-samples were then analyzed for some physical and chemical properties using standard procedures as follows: -

i. Particle size distribution by using the hydrometer method (Gee and Bauder, 1986).
ii. Total nitrogen by kjeldahl method (Bremner and Mulvaney, 1982)
iii. Soil available P using Bray No. 1 method (Bray and Kurtz, 1945; Jackson, 1962).
iv. Organic carbon by modified Walkley – Black method as detailed by Nelson and Sommers (1982).
v. Exchangeable bases by extraction with ammonium acetate. K & Na were determined by flame photometry while Mg & Ca were determined using the atomic absorption spectrophotometer (Anderson and Ingram, 1993).
vi. Effective Cation Exchange Capacity was determined by the sum of exchangeable acidity and exchangeable bases (Anderson and Ingram, 1993)
vii. Soil pH in water and 0.01M $CaCl_2$ in the ratio of 1:2.5 (Soil:Solution)

Greenhouse Procedure

There were 18 perforated pots. Each pot was filled with 14 kg of air-dried soil. The perforation was to allow for free drainage and adequate aeration. Plastic receivers were placed underneath the pots to collect any seepage and subsequently returned back to the pots. Soil in each pot was thoroughly mixed and watered to field capacity before pearl millet seeds (Super sosat) were sown. Five seeds were sown per pot and later thinned to two plants per pot Fertilizer was applied based on the optimum recommended rate of NPK for pearl millet which is 60 kg N/ha, 30 kg P_2O_5/ha and 30 kg K_2O/ha respectively (Ajeigbe et al., 2020)

Treatments And Experimental Design

The treatments (T1 to T6) consisted of 6 irrigation supplies based on the growth and developmental stages of pearl millet as follows:

T1 = No irrigation in the first 13 days after emergence (3-5 leaf stage)
T2 = No irrigation between 14 to 27 days after emergence (panicle initiation stage)
T3 = No irrigation between 28 to 41 days after emergence (boot stage)
T4 = No irrigation between 42 to 55 days after emergence (milk stage)
T5 = No irrigation between 56 to 70 days after emergence (dough stage)
T6 = Full irrigation at field capacity every 5-days interval (control treatment).

Irrigation was provided at field capacity as determined gravimetrically every 5-days interval (Suhailbani, 2011) except during the "no irrigation period" as appropriate for the various treatments (T1 to T5).

The treatments were arranged in a Completely Randomized Design (CRD) replicated 5 times to have 6 x 5 = 30 pots.

Test Crop

The test crop was pearl millet (Super SOSAT variety). Important features of the crop (FAO, 2017; Ajeigbe et al., 2020) are summarized below:

-Name of crop species: *Pennisetum glaucum* L. (pearl millet)
-Variety name: Super sosat (LCICMV-3)
-Original name: PE05532
-Outstanding features: High yielding (≃ 4 t/ha grain).
-Drought tolerant.
-Resistance to downy mildew disease.
-Good food quality.
-Stout stalk for fencing.
-Maturity: 80-90 days.
-Origin: ICRISAT/Mali.
-Developing institutes: LCRI Maiduguri/ICRISAT Niamey.
-Year of release: 2011.
-Year of registration: 2011.

Measurements Taken

Plant height/plant (cm) and leaf area/plant (cm^2) were taken at two weeks-interval. The plants were harvested at 11 weeks after sowing (11WAS) by cutting the plants at 2cm from the soil level. Shoot yield (dry) was determined by weighing with digital weighing machine. For the dry weight, plant samples were washed, rinsed with distilled water and oven dried at 65^0C for 72 hours before weighing.

Leaf area was calculated by the non-destructive length x width method as described by Payne et al. (1991) i.e.

LA = L x W x K, where,

LA = leaf area in cm^2
L = length of the leaf
W = width of the broadest point of the leaf
K = constant (= 0.68 for pearl millet).

Five leaves from sampled plants were randomly selected and measured with a ruler, linearly. The mean was then recorded.

For plant height, five samples of randomly selected pearl millet plants were chosen and a meter rule was used to measure the height at 2 cm from the soil level to the top-most leaf. The mean was then calculated (Saba et al., 2015).

Percentage increase in yield was determined as: $\{(Yield_{trt} - Yield_{control})/ Yield_{control}\} \times 100$

Statistical Analysis

Statistical tools such as ANOVA, Least Significant Difference (LSD) and percentages were used in analyzing the data to derive the various relationships by applying statistical computer package (Microsoft analysis toolpak). Means were separated at 5% Level OF Significance (LOS)

RESULTS AND DISCUSSION

Physico-Chemical Properties Of The Soil Used

Selected Physico-Chemical Properties of Soil used for growing pearl millet in greenhouse trial are shown in Table 1. The, soil was sandy, slightly acidic in reaction with very low content of nitrogen, organic carbon and available P. The cation exchange capacity was also low. This is in accordance with Adamty, (2016); that soils of the Nigerian Savanna are inherently low in fertility and lack the ability to hold good amount of water and nutrients

Table 1: Physico-Chemical Properties of Soil Used

Soil Property	Soil (greenhouse)
Clay	2%
Sand	95%
Silt	3%
Textural class	Sandy
pH (0.01m $CaCl_2$ 1:2:5)	6.4
Organic carbon	0.51%
Available phosphorus	10.51ppm
Total nitrogen	0.04%
Cation exchange capacity	5.25cmol/kg

Effect Of Treatments On Plant Height Of Pearl Millet

The response of plant height to water stress (water deficit) at various growth stages of pearl millet is shown in Table 2. From the result, significant differences in plant height were observed at 3 and 5 Weeks After Sowing (WAS).

Table 2: Response of plant height (cm) to water stress at various stages of growth (Values are Mean ± Standard Deviation)

Treatment	3 WAS	5 WAS	7 WAS	9 WAS	11 WAS
T1	25.3±3.32 a	40.0±4.12 ab	69.3±4.12	92.1±9.74	110.2±10.33
T2	22.3±2.50 ab	35.5±9.06 b	68.7±8.31	106.2±9.73	140.1±7.58
T3	26.0±1.10 a	56.3±8.49 a	70.3±3.16	100.1±10.43	118.7±10.21
T4	15.3±4.70 bc	26.7±3.05 b	58.3±2.24	73.3±7.62	110.3±4.90
T5	12.0±1.73 c	43.7±3.46 ab	68.3±3.32	93.2±10.91	118.0±8.93
T6	14.0±2.11 bc	31.3±3.74 b	55.3±2.88	94.7±10.17	113.7±9.27

Means followed by the same letter(s) within column are not statistically different using LSD at 5% LOS

This implies that water stress significantly affects plant height at early stages of pearl millet development (perhaps at 3-5 WAS). However, the result indicates that pearl millet significantly produced taller plants (compared to control treatment) if drought (water stress) is at boot stage of growth (T3). Taller plants may lead to the production of more forage. Sheahan (2014) recommended the cutting of pearl millet as forage when it is up to 90 cm tall (approximately 8-9 WAS). Hence, it can be said that water stress at later stages of development (7-11 WAS) did not significantly influence the plant height. It also suggests that early harvesting (3-6 WAS) may affect the forage yield while later harvesting favors uniformity in height of the plants

Effect Of Treatments On Leaf Area Of Pearl Millet

In pearl millet, leaf area responds well to water stress (Suhaibani, 2011). Result of the response of leaf area to various water stress regimes can be seen in Table 3. Significant differences were recorded at 5 and 11 WAS, perhaps, during the boot and dough stages of development respectively.

Table 3: Response of leaf area (cm^2) to water stress at various stages of growth (Values are Mean ± Standard Deviation)

Treatment	**3 WAS**	**5 WAS**	**7 WAS**	**9 WAS**	**11 WAS**
T1	13.7±7.75	61.7±6.71 b	102.3±10.95	135.7±10.11	146.3±8.61 b
T2	11.7±7.62	48.0±9.06 bc	129.7±11.45	223.2±10.27	190.7±11.75 b
T3	20.3±0.55	104.2±13.75 a	128.3±11.62	181.3±11.07	207.3±13.38 ab
T4	5.7±1.52	16.1±12.17 c	85.3±13.11	124.4±11.73	170.1±10.58 b
T5	9.7±0.55	54.6±10.17 bc	134.1±11.83	197.3±13.87	281.7±11.53 a
T6	9.3±1.41	30.1±2.53 bc	97.2±5.20	191.2±14.28	182.1±9.17 b

Means followed by the same letter(s) within column are not statistically different using LSD at 5% LOS

At 5 WAS, water stress during the boot stage was significantly superior in producing larger leaf areas than all other treatments while at 11 WAS, leaf area during dough stage (T5) was significantly superior to all other treatments except treatment T3 (boot stage). The result reveals that leaf area is encouraged by water stress during boot and dough stages of pearl millet development. It has been mentioned by Khairwal et al. (2007) that the highest water use in pearl millet is during the flowering (boot) and dough stages of growth. The result indicates that water stress during those periods encouraged subsequent development of leaf area.

Effect Of Treatments On Dry Matter Yield (DMY) Of Pearl Millet

Significant differences among treatments were observed in relation to the Dry Matter Yield (DMY) of pearl millet (Table 4). All the treatments were significantly different to each other.

Table 4: Response of Dry Matter Yield (g) to water stress at various stages of growth (Values are Mean ± Standard Deviation)

Treatment	**Replicate I**	**Replicate II**	**Replicate III**	**Replicate IV**	**Replicate V**	**Mean**	**Standard deviation**
T1	74.1	75.2	73.5	74.2	73.4	74.1 e	± 0.71
T2	67.5	68.7	68.1	68.3	68.4	68.2 f	± 0.45
T3	92.4	91.5	92.5	92.2	91.1	91.9 c	± 0.40
T4	168.3	167.8	166.4	165.9	167.5	167.2 a	± 1.00
T5	86.2	87.2	85.6	86.2	87.9	86.6 d	± 0.74
T6	163.2	162.1	163.3	161.7	162.5	162.6 b	± 0.71

Means followed by the same letter within column are not statistically different using LSD at 5% LOS

From the result, water stress during the milk stage significantly produced the highest DMY and it increased yield by 2.64%. this may be due to the fact that pearl millet is sensitive to water stress at 40-65 days after sowing, thus it may have adjusted itself morphologically, anatomically or biochemically in the first 5 WAS to enable it tolerate the water stress at the milk stage of development (Begne, 2020). Essentially, early water stress (first 27 days) significantly reduced DMY by 54.3-58.0%. The result implies that early season drought may negatively affect final yield of pearl millet. Reports by Begna (2020) indicated that in pearl millet, water stress at dough stage can reduce yield by at up to 50% while early season drought is critical to the plant growth and the yields of the crop are significantly reduced by prolonged water stress conditions.

Generally, water stress significantly reduced dry matter yield by at least 43.5% during all stages of growth except the milk stage. Therefore, water stress is mostly detrimental to pearl millet yields. A study by Aliyu (2022) showed a strong, positive and significant relationship between the dry matter yield of pearl millet and other growth and yield parameters such as grain yield, panicle weight, plant height, leaf area and panicle girth.

CONCLUSION

The effect of water stress at various stages of development in pearl millet was investigated using standard procedures. Results indicated that water stress at boot and dough stages significantly stimulated the growth of plant height and leaf area of the crop. However, the dry matter yield of pearl millet was significantly improved by water stress at milk stage. Therefore, water stress during the boot, dough or milk stage may improve the yield of pearl millet.

RECOMMENDATION

From the findings of this study, it is recommended that pearl millet producers can induce water stress conditions at suitable stages of development (boot stage, dough stage and milk stage) to stimulate and improve the growth and yield of the crop This strategy may help to increase productivity and reduce the cost of production especially in irrigated Agricultural systems. There is need to conduct similar study on other crops in various Agro-ecological zones of Nigeria

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